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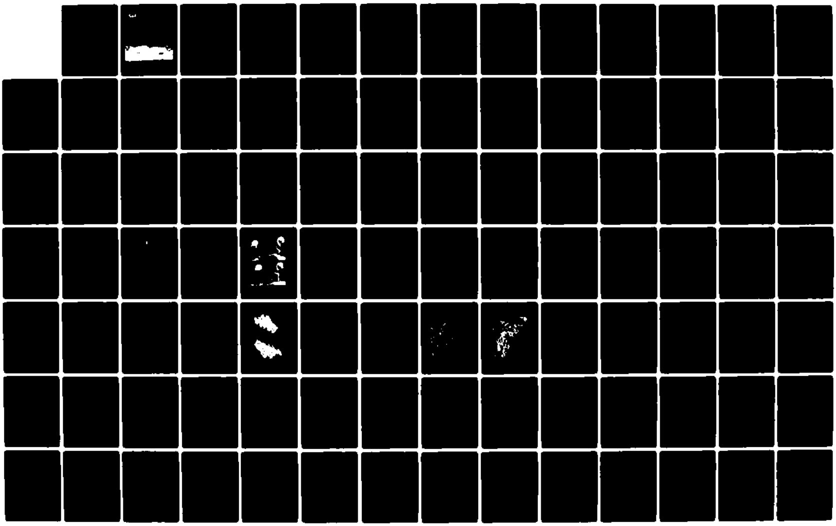

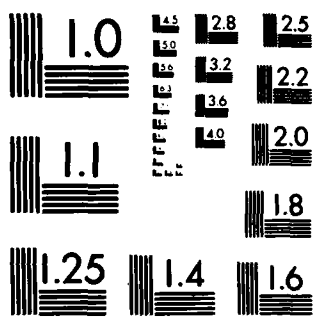
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COMPUTER-AIDED WATERSHED ANALYSIS

by

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> A system was developed to simulate the overland flow of rainfall runoff in a microgeometric model of the landscape. The landscape model was developed from normally available materials by means of a geographic data-handling system. The water flow model provides both direct rainfall and grid-to-grid flow components for every grid on the landscape. The size of the grid, the time increment for analysis, and the rainfall intensity are adjustable by the user.

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20. ABSTRACT (Continued).

> The surface flow is followed in an eight-nearest-neighbor microflow pattern across the landscape until the flow reaches channels within the grids. The system provides flow patterns within the watershed, effective drainage area and runoff curve numbers for every grid, and a complete flow time history for each grid.

The system was developed according to an objective mathematical approach so that it does not require extensive technical knowledge for operation; it was designed to use normally available data at reduced computer operation cost.

This previously unavailable technical procedure is expected to be useful in erosion studies and as an aid in U. S. Army Corps of Engineers construction activities. Military applications include an ability to rapidly assess, for anticipated rainfall conditions, areas with potential cross-country mobility problems induced by storm runoff.

PREFACE

This computer-based system for simulating the overland rainfall runoff at the microgeometry level was developed under the authority of an In-House Laboratory Independent Research Program as Project 4A161101A91D, Task 02, Work Unit 124, sponsored by the Assistant Secretary of the Army (R&D).

The work was performed during 1976-1982 by Dr. Victor E. LaGarde of the Environmental Resources Division (ERD), Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Dr. John Harrison, Chief, EL, and Dr. Conrad J. Kirby, Chief, ERD. Dr. LaGarde developed the system and all computer programs described in this report, and wrote the report.

COL Tilford C. Creel, CE, was Commander and Director of WES during the latter part of this study and the preparation of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
acre feet	1233.489	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
inches	2.54	centimetres
miles (U. S. statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
square miles (U. S. statute)	2.589998	square kilometres
tons (short, 2000 pounds)	907.1847	kilograms
yards	0.9144	metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

COMPUTER-AIDED WATERSHED ANALYSIS

PART I: INTRODUCTION

Background

1. The U. S. Army Corps of Engineers has the responsibility for handling a wide range of water resource and environmental problems. One type of information consistently required in handling these problems is data on the overland flow of storm rainfall and on the volume of water moving in the stream networks of a watershed.

2. Data on overland flow, water moving across the surface of the ground outside stream channels, are essential for the calculation of erosion. Erosion problems are prominent in regions where the surface soil material is not well stabilized to the water movement. This includes arid and semiarid regions; locations where the stabilizing vegetation cover is disturbed or covered with material moved from another location; and regions where little or no disturbance has occurred, but the overland flow regime is changed through structural or land use modifications of the landscape.

3. There are significant and extensive erosion problems associated with the everyday intended use of military bases for training exercises, problems that are faced by the facility engineers. However, the Corps becomes involved with erosion problems primarily in the planning stages of proposed water control projects in Corps District Offices. Concern with erosion centers about (a) the increase in sediment load carried by streams and (b) the detrimental effects on stream water quality due to increases in suspended sediment and the deleterious chemicals and materials that could move with eroded materials into the streams as a result of proposed Corps construction projects.

4. The Corps is responsible for terrain analysis for military purposes and has performed a significant amount of work in studying the effects of the terrain on military operations and material. For example, this work has included cross-country movement evaluations of vehicles.

The results of combat simulations used in studying the introduction of new-design equipment for Army combat use are very sensitive to vehicle cross-country movement capabilities, which in turn are very dependent on the engineering properties of the terrain. These engineering properties vary greatly with soil-moisture conditions on the landscape. It would be very helpful to have the capability to calculate storm-induced surface flow at a finer level of detail than is now possible.

5. An extensive amount of work has been performed on erosion problems, particularly by the U. S. Soil Conservation Service (SCS) on reliable methods to evaluate erosion problems. Verified procedures have been developed to account for the cross-surface movement of eroded material and for movement of material into the streams. A major problem involved with the use of the procedures is that they are manual-labor-intensive in use, relying on field observations of runoff water movement into and out of the areas of erosion concern. A second and more serious problem associated with the manual-labor-intensive procedures is that they are used to calculate aggregated results; that is, the results are calculated for large areas without any detailed knowledge of the flow patterns within the regions. The first step needed to make the procedures (a) more tractable and economically justifiable for use over extensive project areas and (b) more useful for studying the flow patterns within the areas is to provide an automated procedure for calculating the runoff water movement into and out of microregions of the total watershed.

6. In addition to erosion-associated problems, the Corps is continuously involved in solving problems associated with water moving in the stream networks of a watershed. Corps District Offices have, in the past, used many different hydrologic and hydraulic procedures to arrive at an estimate of the stream hydrograph for a given storm event. Over the recent past, the use of the U. S. Army Engineer Hydrologic Engineering Center (HEC) computer programs HEC-1 and HEC-2 has become more popular to provide these data. These programs have provided the Corps with a more standard procedure, with results which are easier to assess in the formal Corps study review process than those of other methods. In

the HEC procedures, a watershed is divided into subbasins and the subbasins into minibasins which consist of regions with approximately uniform hydrologic and hydraulic characteristics. The locations at which hydrograph data are available are essentially the locations where the water moves out of a minibasin into a channel. It would be more helpful in many Corps studies if the arrangement of the minibasins could be easily modified, and if hydrographs were available at locations other than the downstream ends of minibasins.

7. For example, Corps Districts are responsible for granting permits for construction and any other work resulting in water regime modification performed in, or adjacent to, a waterway or wetland. The Corps' regulatory authority extends up to the location on a stream where the mean flow rate is 5 cfs.* At present, this location is estimated by first attempting to calculate the size of watershed needed to provide a 5-cfs flow rate based on generalized data for the region. Once the estimated area of the region is known, the 5-cfs flow rate position is located by repetitively moving upstream and downstream and calculating the areas of watersheds feeding the stream at selected locations until that position on the stream is located for which the watershed is the proper size. While this procedure produces an approximate answer, the magnitude of the inaccuracy is unclear. It is necessary to base the procedure on several levels of estimates because a flow model that directly provides streamflow rates at closely spaced intervals is lacking. The first step needed to resolve this problem is to provide an automated procedure for calculating water movement over a network of small regions so that the flow in the stream can be calculated at a fine interval along the stream, and the 5-cfs flow position can be located with more accuracy and without the need for repetitive calculations.

8. In solving both civil and military erosion and streamflow problems, the key to technical improvements in current procedures is the ability to segment a region into small areas and follow the movement and

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* A table of factors for converting inch-pounds units of measurement to metric (SI) units is presented on page 3.

aggregation of water between areas as it moves to the stream channels. The use of gridded data in a geographic information system provides the framework for accomplishing this objective. A geographic information system with a regular grid provides a well-defined network of small areas so that each grid can be assigned the data required for calculation of water movement through a grid, and from that grid through adjacent grids to the stream channel.

9. The use of geographic information systems is gaining acceptance in Corps Districts, and District personnel are becoming aware of their potential uses. U. S. Army Engineer Waterways Experiment Station (WES) routinely uses geographic information systems in District Planning Division Survey and General Design Memorandum studies associated with water control projects, and in estuaries studies. Geographic information systems have been in use in military combat and weapons system analysis studies and combat contingency studies for years.

10. The study described in this report is an attempt to extend the use of these general procedures to additional aspects of water resources studies that Corps District and combat engineer personnel encounter, both in civil and military work. Listings of the computer programs specifically mentioned in this report can be obtained from the author.

Purpose

11. The purpose of this project was to develop a gravity-flow type computer simulation of the movement of storm rainfall runoff within a watershed. The form of data for the surface runoff calculation is a regular grid network model of the watershed, with each grid within the watershed containing the data describing that microregion of the watershed. Major objectives of the development included (a) the use of normally available data and (b) the reduction of the problem to a form that permits a solution within a reasonable timeframe and cost.

PART II: TECHNICAL BACKGROUND

12. Hydrologic calculations are based on certain physical properties of rainfall, soil composition, soil cover, and topographic relief. An understanding of the relationships between these physical properties and rainfall runoff has matured considerably over the past three decades so that the rationale of the general approach to hydrologic calculations is not difficult to understand. However, the complexity of hydrologic calculations has increased considerably as more modern tools have been made available both to derive more accurate interrelationships between the physical properties and rainfall (because of improved empirical data and technical knowledge advances) and to perform the hydrologic calculations with the ability to consider the physical property relationships in more detail.

13. This part of the report describes the technical background underlying the approach taken in this development study and carries the reader to the point where the calculations described in report Parts III and IV can be understood. Part III provides a detailed description of how required data for all parameters are compiled and handled, and Part IV describes how the flow calculations are performed.

14. An overview of the hydrologic calculation procedure showing the rational connections between data and calculation operations is shown in Figure 1. The overview provides a vehicle for a description of the calculation background.

15. It is recommended that the reader who is not familiar with traditional hydrologic calculations read this part of the report twice. Unfortunately, data used for hydrologic calculations are quantified principally through classing the data and assigning quantitive values to the classes. While the assignments to classes are intuitively acceptable, the values are understandable only in the context of how all the data are interrelated in the hydrologic calculation. The values assigned to the classes are understandable only by following the analysis of empirical data. The analysis of empirical data is beyond the scope of this report.

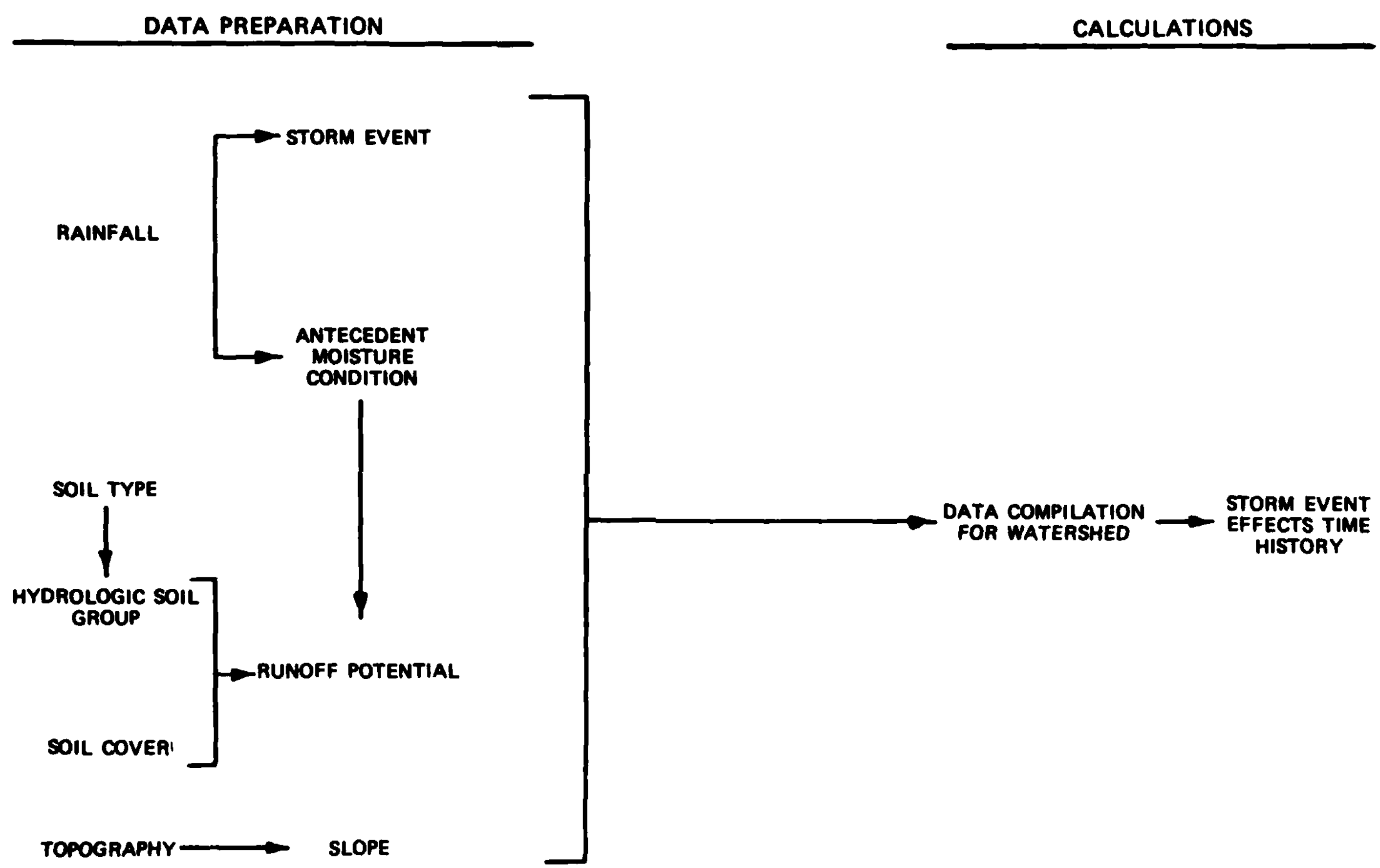


Figure 1. Overview of rational connections between hydrologic data and hydrologic calculations

16. Readers familiar with hydrologic calculations will recognize this part of the report as a modest attempt to summarize only those aspects of hydrologic engineering required to wade through the successive parts of this report. Brief engineering excursions are also provided in the Parts III and IV to further explain this technical background where appropriate.

Rainfall Data

17. Rainfall information is derived almost solely by empirical means. Weather stations and the National Weather Service publications are the normal source of rainfall data. The rainfall data required for a hydrologic calculation consist of the accumulated rainfall quantity in inches of rainfall as a function of time. The development of rainfall data for a given region is complicated by the fact that locations of rainfall gaging stations are few and far between, and have limited historical records of rainfall. The development of a rainfall record for a real single storm event for use in a hydrologic calculation is no problem provided that a gage exists within the watershed and the gage record is acceptable for use.

18. Practically all hydrologic calculations are performed using simulated rainfall events derived on the basis of a statistical study of historical gaged rainfall events. Since most hydrologic calculations are performed as part of an engineering study in the design of water conveyance works or flood protection works, simulated rainfall records (and hydrologic calculations using those records) are required for several storms of different magnitudes. The storm magnitudes are chosen because there is a requirement to design construction works for, or protect against, a given storm event. A popular storm event frequently encountered in studies is the 100-year event; i.e., that rainfall which produces a flood which statistically will occur once every 100 years. For example, the Federal Flood Insurance Program, which provides the opportunity for property owners to join in a special flood insurance program, is directly related to whether their property is judged to lie

within the region flooded by a 100-year storm event in their local area.

19. When the engineering planning study involves the evaluation of different designs to plan the most cost-effective construction, hydrologic calculations are performed for several storm events. The several storm events are chosen to provide a sufficient definition of the flood-frequency regime, so that quantities such as "stream discharge," "stream water elevation," and even predicted flood damages can be adequately described as a function of anticipated flood probability of occurrence. In agricultural areas, it is the high-frequency storm events such as the 5-, 10-, and 15-year events that are of particular interest.

20. The preceding short description of potential uses of hydrologic calculations shows that the interest in storm events spans the entire range of possible events.

21. The construction of a rainfall record for a simulated storm event involves the definition of the shapes of (a) the rainfall intensity function, (b) rainfall duration, and (c) total cumulative rainfall. While soils types and land-use patterns and other conditions that affect rainfall runoff are measurable and the accuracy of the measurements easily determinable and readily understandable, the same is not true for synthetic storm data. Because of the uncertainties involved in calculation and the critical role that the rainfall function serves in many types of engineering design studies, a mature technical capability has developed. U. S. Weather Bureau (1955), Hershfield (1961), Soil Conservation Service (1972), Randolph and Gamble (1976), and Colson and Hudson (1976) give background information, specific statistical procedures, and examples of rainfall data and their use that go far beyond the scope of this report.

22. Rainfall data are often required in regions where there are no rainfall gages. Data derived from statistical analyses are available for estimating the error (and even the error function) for an ungaged region based on the distance of that region from the nearest neighboring rainfall gage or gages. In addition, information is available for correcting the rainfall data for the difference in elevation between the study and gaged watershed. Sometimes the study watershed is delineated into

subwatersheds, and different-intensity storms are simulated in different subwatersheds for the same storm event to account for differences in internal intensity within the same storm. This is done to account for the statistical probability that the storm's local intensity increases with decreasing subwatershed size.

23. The experience of the hydrologic engineer in the local area for which the hydrologic calculation is being performed is the decisive factor in producing the required rainfall information from data such as that given by U. S. Weather Bureau (1955), Hershfield (1961), SCS (1972), Randolph and Gamble (1976), and Colson and Hudson (1976) for the state location of the particular watershed.

24. The system described in this report will operate with any rainfall data.

Antecedent Moisture Condition

25. The rainfall in a 5- to 30-day period prior to a specific storm event is used as an indication of a watershed wetness at the start of the storm event. Watershed wetness is related to the infiltration rate. The antecedent moisture condition of a watershed is normally ranked as low, average, or high, where these conditions are defined as follows.

Antecedent Moisture Condition	Definition
I: Low	The watershed soils are dry enough for plowing and cultivation
II: Average	The normal condition
III: High	The watershed is near saturation from previous rainfall

26. Since soil wetness after rainfall is dependent on evaporation and transpiration rates, which are in turn related to the temperature regime and the growing season, the antecedent moisture condition for any given location varies through the year even if the rainfall history

remains unchanged over the year. A given rainfall history in the growing season that would result in an "average" condition would normally produce a "high" condition in the dormant season. The average condition for the crop season is normally used in hydrologic calculations because it is the crop season with attendant storm-induced agricultural damages that is normally studied; statistically derived storm conditions are usually used because of the emphasis on hydrologic calculations in the flood planning and protection studies that are the ultimate goal of a study. The average condition was assumed for this development effort, and all calculations were performed with this assumption. Either of the other two antecedent moisture conditions could be used in the developed procedure calculations without any modifications; however, a change must be made in the rainfall infiltration relationships, which change (usually by a small amount) from one antecedent moisture condition to the next.

Soils and Hydrologic Soil Groups

27. The rainfall runoff for any given location in a watershed is dependent on the soil properties (among many parameters) at that location. This relationship is considered indirectly in the runoff calculation by classifying the soils in a watershed into hydrologic soil groups according to their minimum rate of infiltration for a base soil after prolonged wetting. Both soil surface and horizons are considered in the assignment of a soil to a hydrologic group. The soil surface cover is treated as another runoff-influencing parameter.

28. There are four hydrologic soil groups with the following broad definitions:

a. Type A: low runoff potential. Soils with a high infiltration and transmission rate, which are generally well to excessively drained, with high sand and gravel content.

b. Type B: low-to-moderate runoff potential. Soils with a moderate infiltration and transmission rate, consisting primarily of well-drained soils without flow-impeding horizons and with moderately fine to coarse textures.

c. Type C: high-to-moderate runoff potential. Soils with low infiltration and transmission rates, primarily caused by shallow horizons that impede water flow, and soils with a moderately fine to fine texture.

d. Type D: high runoff potential. Soils with very low infiltration and transmission rates. The soils typically (1) have a high clay content, are located over a high water table, are associated with a claypan or clay layer at or near the surface; or (2) consist of shallow soils over an impervious layer.

29. Many soils have been assigned to a hydrologic soil group based on rainfall and runoff data from test plots and watersheds with close to single-soil properties. Most soils have been assigned to a group based on a comparison of their soil profiles and physical properties with those of previously classified soils. The assignment of a soil to a group is made assuming a base-wetted surface and a rainfall exceeding the infiltration capability of the soil in order to make the assignment insensitive to the infiltration that occurs prior to runoff. For this reason, short intense rainfall occurrences such as that associated with the largest yearly storm are used in classifying soils.

30. Subgroups of the four broadly defined hydrologic soil groups normally are not used due to the lack of sufficiently refined rainfall, runoff, and soil data and the general insensitivity of the hydrologic calculation to this parameter.

Land Cover

31. The infiltration of rainfall at a given location is directly related to the soil type and land cover of the soil surface. The land cover is normally classed as a combination of land use and land treatment practices that apply primarily to agricultural practices. Table 1 contains a simplified form of the basic land cover classes that are most commonly used. Table 1 also contains curve number data that are described in paragraphs 43-61.

32. The following descriptions highlight the physical significance of the class system that is used as regards the relationship between infiltration and land cover.

33. Fallow land in a crop rotation use pattern has a high runoff potential. The land is kept as bare as possible, with a light vegetation cover to conserve moisture and provide protection of the soil from direct raindrop impact and wind, and therefore maintains a higher moisture content than would be found with crops. The evapotranspiration rate is the primary limiting factor on moisture content.

34. Row crop use is characterized by a spacing between vegetation that permits most of the bare soil surface to receive the direct impact of rainfall. Cotton and soybeans are row crops. Contoured rows impede the flow of runoff and provide an increased potential for infiltration by causing surface storage of the runoff. Terraced cropland further impedes runoff by reducing the slope of the ground so that the lag in time between rainfall contact and outflow from the area is increased and more rainfall infiltrates during the water movement.

35. Small-grain planting such as wheat and hay provides an almost complete cover over the soil.

36. Crop rotations vary from broadcast planting of legumes and grasses to continuous planting of a single crop. Legume and grass rotations increase tilth and the infiltration rate, while single continuous cropping is equivalent to row or small-grain crop planting.

37. Woodland refers to managed timber production type woods. The level of ground cover effectiveness the woodland class provides to rainfall and rainfall runoff is determined by the amount of litter, small tree, and brush plant cover beneath the trees and whether the area is or is not grazed or cleared. The timber production of the woodland has no bearing on the ground cover properties.

38. The difference between hay and pasture grassland is primarily the soil compaction caused by grazing animals. Crop and pasture grassland vary in cover effectiveness depending on the density of vegetation growth. The measurement of biomass density is a procedure sometimes used to refine the grassland runoff information. Soil compaction of pasture grassland is a function of prevalent soil moisture conditions. Dry soils, with larger cone indexes and load-bearing ratios, do not compact as easily as the same soils in moist condition. Permanent grassland

includes cropped or pastured grassland that has remained idle for several years.

39. Compacted and covered lands include all those with infiltration characteristics modified by human use so that the soils are permanently compacted by human or machine traffic, or covered with an artificial surface that modifies the runoff characteristics regardless of the underlying soil type or surrounding land cover. Several compacted and covered land cover classes are shown in Table 1.

40. Table 1 is included in this report as representative of the land cover classes described by sources such as SCS (1972). A critical review of the classes in Table 1 shows that the categorization system is not strictly proper and contains what appear to be gaps. For example, "row" and "contoured" croplands are not mutually exclusive classes at the same categorization level, and it is possible to have other than "row" fallow ground. Table 1 is, however, representative of the data used in studies; the important concept to remember is that the land cover categorization provides a means of defining the different runoff characteristic land in the study region.

41. The primarily agricultural land cover classes shown in Table 1 (fallow through grassland) are usually further refined by an evaluation of how well the land cover treatment lends itself to increasing infiltration. For example, a one-crop continuous rotation system provides more runoff than the planting of a broadcast legume and small grain type rotation. The infiltration rate for different land use and cover conditions used in a hydrologic calculation is modified to account for the practices in the local area where the hydrologic calculations are being performed. In practice, the modification is based on experience in calibrating hydrologic calculations to historical storm records in preceding hydrologic studies for other watersheds.

42. The term "land use" is almost always used to connote land cover; land use is so used in the remainder of this report.

Curve Number Parameters Use

43. The curve number parameter procedure for calculating storm runoff is described in this section of the report. This procedure has several important advantages. It incorporates the technical knowledge of the runoff process and makes direct use of a significant body of empirical data gathered over previous years. It permits the extrapolation of the runoff calculation procedure to watersheds for which there are little data, except for similarities between the watershed of interest and other nearby watersheds for which there are data. The approach provides for considerable objectivity in performing a runoff calculation, so that results are reproducible without resource to highly trained specialists. Finally, the identical approach can be used whether little is known about a watershed, or the watershed has been the subject of extensive investigation and a significant body of detailed data is available. The more detailed the available data, the more accurate a value for the curve number can be calculated for a given position in a watershed. The approach permits the substitution of data from various sources. For example, the use of Landsat-derived land use data in place of aerial photograph interpreted data has been demonstrated as an acceptable solution in many nondetailed studies of the type performed by the Corps.

44. The procedure is limited to the extent that it was originally developed by the SCS for use with agricultural lands, and most data refinement work has been carried out by the SCS, which has an interest primarily in agricultural areas.

45. Although the terminology differs among papers in the literature, the storm runoff that reaches a stream and contributes to the stream discharge originates as overland, subsurface, base, or channel flow.

46. Overland flow consists of the water flowing on the ground surface. This flow comprises the rainfall remaining when the rainfall rate exceeds the infiltration rate, and rainfall interception and storage conditions have been exceeded.

47. Subsurface flow is the movement of infiltrated rainfall in the upper soil layer; i.e., the lateral flow of water through upper soil horizons normally above the groundwater level.

48. Base flow consists of the infiltrated rainfall that percolates to the permanently saturated groundwater flow system. At this depth, the soil or rock pores are filled with water at a fluid pressure greater than atmospheric pressure, so that this level starts at the water table.

49. Channel runoff consists of the rainfall that lands directly in the water-filled stream channels.

50. Comparing the lag times of the different rainfall runoff components shows that the channel component flow as a function of time is identical with the rainfall intensity as a function of time. The overland flow component arrives at the stream channel at a slightly later time, the subsurface flow at an even later time, and the base flow at a significantly later time. "Later time" is used to connote the peak flow amplitude of the flow-component time history. In addition to the delay in the flow function amplitude peak, the trailing edge of the flow function is increasingly protracted as the flow time increases. The base flow is protracted to the extent that effects on streams in nonarid environments can be measured days after the producing storm subsides.

51. In practice, it is difficult to separate the overland and subsurface flow components because of insufficient empirical data. The curve number procedure as used in this study applies to the sum of the overland and subsurface flow components, which is called "surface flow" throughout the remainder of this text. Given two otherwise identical pervious surfaces, the overland flow component is greater on the more impervious surface.

52. The channel runoff component is a trivial (flow calculation) case for the runoff procedure, but it is ignored in this study because the interest is in flow over land. The reader should not confuse channel runoff flow with channel flow, which is frequently mentioned later in this text. This latter flow involves movement of water in the stream channel.

53. Base flow is ignored in this study.

54. The following is a brief derivation of the rainfall runoff equation. Flow lags are ignored in this derivation to provide the basic concept without confusing the derivation. The derivation proceeds, therefore, as if the rainfall were the total cumulative value for the storm (this is another way in which the derived relationship can be used, as will be seen in Part IV of this report).

55. Conservation of mass requires that whatever rain falls onto the land must flow off without loss or gain of water. Note that the words "flow off" are used in a loose sense to mean the removal of rainfall to its final fate by whatever path. The reader should suspend disbelief through this short derivation and be assured that disquieting effects such as evapotranspiration will be neatly (almost) resolved in the end. Because of the requirement for conservation of mass, the ratio of the runoff to the rainfall is equal to the ratio of the actual retention of water by the land to the total potential retention by the land. This can be graphically demonstrated by plotting cumulative rainfall versus cumulative runoff for any storm with an intensity great enough to overcome the initial loss of water to all combined effects (i.e., the abstraction term). Such a plot shows that the relationship between these two lines becomes a straight one-to-one slope straight line after initial rainfall losses are completed. The equation for the basic relationship is as follows

$$\frac{(R - Ia) - Q}{S} = \frac{Q}{R} \tag{1}$$

where

R is the rainfall

Ia is the initial abstracted rainfall amount

Q is the runoff

S is maximum potential amount of rainfall that could be retained by the land, and includes the effect of abstraction indirectly just as the abstraction term is shown overtly in the numerator

(R - Ia) - Q is the water actually retained by the land

56. The units of measurement are inches of water. Solving Equation 1 for the runoff yields the following equation.

$$Q = \frac{(R - Ia)^2}{R - Ia + S} \tag{2}$$

57. The initial abstraction term Ia accounts for losses before runoff begins. This term includes, therefore, the interception, infiltration and storage, and surface storage effects. The relationship between the maximum potential amount of rainfall that could be retained and the initial abstraction term has been derived from experimental small watersheds as $Ia = 0.2S$; substituting this into Equation 2 yields the following

$$Q = \frac{(R - 0.2S)^2}{R + 0.8S} \tag{3}$$

58. In order to provide a convenient procedure for calculating the runoff value Q , the curve number CN is defined so that

$$CN = \frac{1000}{S + 10} \tag{4}$$

Note that $CN = 100$ when the maximum potential rainfall that could be retained is zero. The curve number for impervious surfaces such as water and plastic is 100; as the potential maximum retention capability of a surface increases (i.e.,as s increases), the value of CN approaches zero. Therefore, the range of CN is

$$100 \geq CN \geq 0$$

and the greater the value of CN , the more impervious the surface and the greater is the rainfall runoff for a given storm. Substituting Equation 4 into Equation 3 provides the final equation form

$$Q = \frac{(R - 200/CN + 2)^2}{(R + 800/CN - 8)^2} \qquad (5)$$

Note that the squared term in the numerator is evaluated only for values of R and CN such that the term is positive. When the term is negative, the initial abstraction of water effect has not yet been satisfied and there is no runoff.

59. Examples of curve numbers for various land use and hydrologic soil groups are given in Table 1. A family of curves that are solutions to Equation 5 is shown in Figure 2 for cumulative rainfall amounts up to 12 in. Most hydrologic engineers are familiar with these curves. A brief inspection of Figure 2 shows some of the properties previously mentioned. Only the $CN = 100$ curve has no abstraction term; for all other curves, $Q = 0$ up to some value of R greater than zero. The larger the curve number, the larger is the percentage of runoff for a

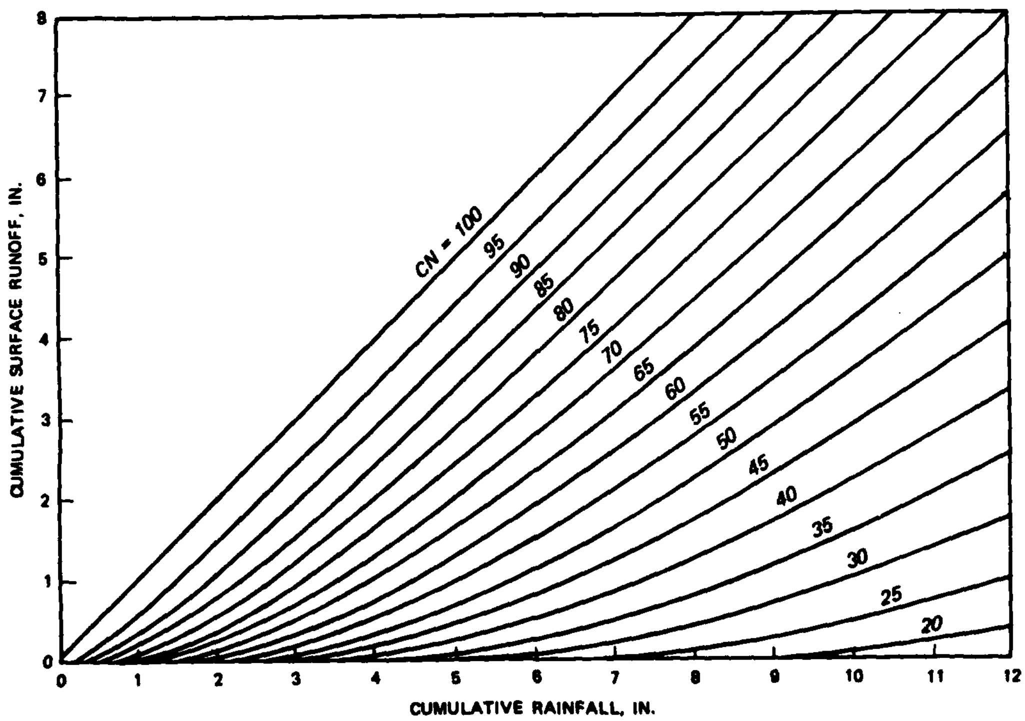


Figure 2. Family of rainfall runoff curves

given cumulative rainfall. All curves have a limiting slope of 1; the larger the curve number, the faster this limiting slope is reached.

60. The empirically derived Equation 6 infers that the infiltration occurring after abstraction has taken place is 80 percent of the potential maximum retention. The physical properties that control this retention are the infiltration at the soil surface, the rate of water transmission through the soil column, and the water storage capacity of the soil column. These properties, for a given soil and land use condition, are controlled by the moisture conditions antecedent to the storm. Statistical studies have shown that the value of S is reduced as rainfall continues over a protracted period, but that it stabilizes after a few days of rainfall. Likewise, when rainfall ceases for several days and the soil column dries out, the value of S increases and stabilizes. This general condition is violated only in anomalous situations, such as extensive deposits of fat clay at the ground surface. The upper range of S corresponds to the lower bounds of antecedent moisture condition I, and the lower range of S corresponds to the upper limit of antecedent moisture condition III. The example curve numbers in Table 1 are for the antecedent moisture condition II, average conditions; similar examples could be presented for high and low antecedent moisture conditions. Curve numbers for these other conditions are also derived from statistical studies of empirical data. The net result is that Equation 5 is used for all antecedent moisture conditions, but the curve numbers are modified slightly to account for different conditions.

61. In summary, the rainfall runoff curves are a set of essentially empirically derived relationships among the physical properties of hydrologic soil type, land use, antecedent moisture condition, and the rainfall runoff. The assignment of a curve number to conditions involving definite values of those physical properties is based on empirical data in such a way that first-order effects of evaporation, evapotranspiration, interception of rain by vegetation, etc., are indirectly accounted for in the assignment.

Lag

62. If a short, intense pulse of rain were released onto a single point on the land, there would be a delay between the time of release and the time that the peak of the surface runoff arrived at a given point in its downstream flow path. The "given point" of interest in this study is the location on the stream channel where the surface flow reaches the channel and converts from surface to channel flow. The delay is the travel time for that pulse of water. Note that the surface flow resulting from a rainfall pulse that ideally starts and stops instantaneously and lasts only a very short time stretches out as it flows across the landscape, and that the travel time is the time for the peak of this flow curve to arrive at the given point. If a short, intense pulse of rain were released onto a portion of, or onto the total, watershed, there would be a delay between the time of release and the time that the peak of the surface runoff arrived at a given surface point in its downstream flow path. This delay is the lag for the portion of, or total, watershed over which the water was released. Therefore, the lag is the flow-weighted average surface runoff travel time.

63. The same parameters, hydrologic soil type, land use, and antecedent moisture condition, along with the topographic slope, influence the speed at which the surface flow moves at any given location. A convenient relationship involving the curve number parameter has been developed.

$$L = \frac{\ell^{0.8}\left[(1000/CN) - 9\right]^{0.7}}{1900\sqrt{S}} \tag{6}$$

where

L is the lag in hours

ℓ is the hydraulic length of the area of flow in feet

CN is approximately equal to the curve number

S is the average topographic slope of the area

Infiltration and runoff and velocity of runoff are not related in

exactly the same manner to the curve number. As an extreme example, a base-compacted soil has a low CN value but a small travel time. The value of CN used for runoff calculations can be used in the lag calculation provided that it lies in the range $50 \leq CN \leq 95$.

64. A watershed can be delineated into subbasins, and the subbasins into smaller catchment units; Equation 6 can be used on the smaller units so that the meaning of lag approaches the meaning of travel time. In practice, there is a limit to the minimum size of unit that can reasonably be used in any study conducted for any engineering planning or design purpose, so that Equation 6 is never actually substituted for the travel time.

PART III: DATA PREPARATION AND PROCESSING

65. This part of the report provides a step-by-step description of the data preparation and processing necessary for compiling all required data.

66. The data preparation and processing take place within the framework of a geographic data base handling capability. This capability was developed specifically for the type of calculations involved in this study, but it is applicable to a wide range of hydrologic, hydraulic, and other studies. The capability was developed to the point where the user needs to know only a few facts regarding the data preparation mechanics, and several simple rules and operating procedures for optimizing the preparation of data. The rules and operating procedures are described in this part of the report, with a description of how specific data are to be handled. The instructions for digitizing data are an exception to this method of treatment due to (a) the length of the required description and (b) the emphasis placed on the high level of quality control during the digitizing operation, which involves data recovery and input to the computer, to ensure that all subsequent computer-based operations will be successful. The digitizing instructions are provided in the first sections of this part of the report, and an overview of the geographic information processing steps is provided immediately following the digitizing instructions. It is essential for the reader to generally understand these sections prior to reading the subsequent sections involving the use of the geographic information system in this study; not only does use of the geographic information system make the total study calculation process possible, but it also incorporates scaling, rectification, multimap handling, editing, and internal data control mechanisms that immeasurably simplify the total process. Listings of the computer programs mentioned herein can be obtained from the author.

67. The data processing performed in this study is described in subsequent sections of this part. These sections provide a record of how the actual data used in this study were prepared and processed.

Description of similar processing procedures that are more restricted in scope are provided in an earlier report (LaGarde and Smith 1976) and a thesis performed under the author's direction (Ma 1978). This study was performed using data that are (a) normally available for and used in hydrologic calculations and (b) from sources that are normally used by Corps District offices. Therefore, the described procedures are not site- or study-specific.

68. The data processing work is increasingly automated as it proceeds through several successive steps. As the level of automation increases, the need for a detailed knowledge of the computer procedures decreases; therefore, the description of the process provided in this report stresses the first steps in the chain of operations. The computer programs used in the different steps check and recheck the input data and standardize the data form and format. The system was designed so that correct completion of the first steps ensures success in successive operations.

Factor Map Digitizing

Factor Maps

69. A factor map is a representation of the areal distribution of data which consist of equivalued regions. The regions, frequently called "patches" because of their appearance on the map, are defined by delineating the boundaries between all patches. Soils, slope, and hydrologic soils maps are examples of factor maps.

70. The aerial distribution of data on any factor map can be recovered in a form suitable for computer processing through the use of a digitizer. Sufficient information is input during the digitizing process to enable subsequent computer calculations to identify the type of data, rectify it (see restrictions in paragraph 74), scale and rotate it, and register it geographically. The implication of these capabilities is that the identical digitizing procedure is used regardless of number of maps used to cover the study watershed, the scale or location of the maps, or whether the maps are or are not rectified to a Cartesian coordinate system on the Earth's surface.

71. There is an emphasis on data quality control and accuracy in the developed procedures. This is partially achieved by making the data recovery portion of the processing (i.e., the digitizing of the data) easy to understand. It is achieved also by making the total processing system as automatic as possible by providing the maximum number of required inputs to the system during the digitizing process. Primary emphasis is placed, therefore, on simple formal rules for digitizing and on the automatic editing of the digitized data.

Digitizing Procedure for Factor Maps

72. Digitizers are used to record XY-coordinate data and any other alphanumeric data desired by the user. Digitizers are provided with either a keyboard or a menu for use in recording all data other than XY-coordinate data. The procedure described in this report is intended for use with a keyboard-equipped digitizer. A similar procedure for use with menu-equipped digitizers, involving more work in digitizing and data processing, is available from the author of this report.

73. It is important to note that only numeric data are recorded using the keyboard. These numeric data consist principally of a code system interspersed within the XY-coordinate and other numeric data. The code system identifies strings of data in the digitized data file and is used by subsequent computer programs in the processing operations for identifying the processing that must be performed and for routing the data.

74. The digitizing procedure consists of two steps.

a. Step 1: Positioning the map. Tape a base map onto the digitizer surface, making sure that the four corners of the base map are within the active surface region of the digitizer and that the bottom boundary of the base map parallels the X-axis of the digitizer surface. This is best accomplished by lightly taping the lower left corner of the base map and noting the Y-digitizer coordinate value for the map's lower left corner. The map should then be rotated so the lower right and lower left corners have Y-digitizer coordinates that agree within a few hundreths of an inch. Note that the map corners are those formed by the boundary around the map's inner area as shown in Figure 3. When the bottom boundary is properly positioned, all four map

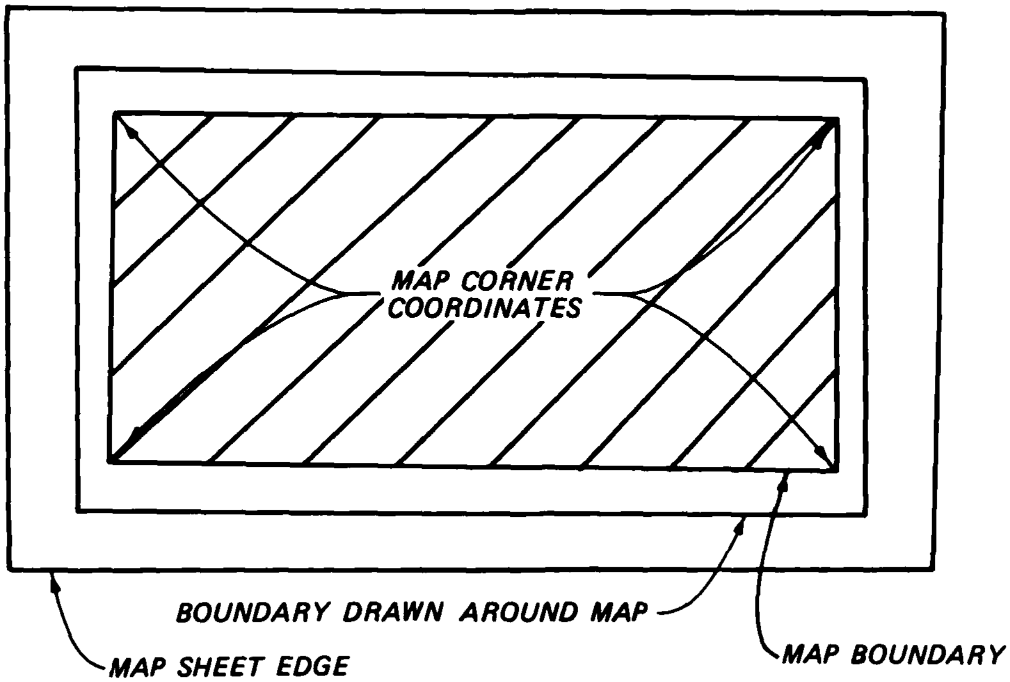


Figure 3. Map corner coordinates

corners should be taped and the bottom boundary rechecked to see that it is still parallel to the X-axis. Note that the base map <u>must remain fixed</u> in this position as long as data are being digitized from it.

b. <u>Step 2: Performing the digitizing.</u> Follow the digitizer format for factor maps shown in Table 2. The following comments are provided to clarify these steps:

(1) Figure 3 shows the layout of information on most maps. All U. S. Geological Survey (USGS) and Corps of Engineer-produced topographic maps have this layout.

(2) The digitizing procedure involves working with one map at a time. The order in which the maps for a study site are handled is immaterial since the geographic reference information provided during digitizing is used by the developed system for locating the map data.

(3) Different maps for the study site, or different types of data on different map overlays for the same map may be positioned at different places on the digitizer surface. There is no need to place all maps at the same location on the digitizer surface.

(4) The recording of data for the map patches is performed in the same manner for all patches regardless of size or shape. The data for each patch consists of a negative code (NCODE) and value or identification for the patch (NVAL) (see Table 2) followed by the coordinates of the patch boundary. The negative code signifies the start of data for a new patch. The coordinates of the patch boundary (see Table 2) are recorded such that the patch boundary is represented as a series of straight line segments drawn between sequential sets of coordinates.

(5) Digitizer operators have a tendency to take too much data when learning how to digitize factor maps. The number of data points needed to define a patch boundary consists of the number which, when connected with straight lines, will adequately represent the boundary (e.g., a rectangular patch requires only four recorded points). The recording of extra points along a patch boundary will not adversely affect the operation of computer programs that use the data unless the amount of extra data is excessive. More important, the recording of excessive data makes the probability of data errors increase significantly and makes correction of errors more difficult and time-consuming.

(6) Digitizing errors are unavoidable, and the best practice is to keep the errors to a minimum by any means. When an error is made, the operator almost always realizes it shortly after the event. A log should be kept while digitizing to record progress and note errors that must be corrected. A sample log format is shown in Figure 4. A copy of the log is used to aid in quality controlling the data after they are placed on a computer file; the description of the error should permit location of the erroneous records.

(7) Every patch on a factor map is delineated, by definition, by a closed boundary. Computer programs that use the digitized data expect to connect the last point digitized on the boundary line to the first point to close the boundary. It is most important to remember to stop digitizing at a location on a patch boundary so that a straight line connected from the last to the first point will close the boundary. Under no condition should the end of the digitized boundary overlap the start.

(8) The first record contains a code number used to identify the data being digitized. All data of the

DIGITIZER OPERATION LOG - FACTOR MAP DATA

OPERATOR NAME:______________________________DATE:________TIME:______

DIGITIZER TYPE AND LOCATION:____

FACTOR MAP	PATCH	COMMENTS

Figure 4. Sample digitizer log format

same type must be identified with the same code number since subsequent computer operations identify, route, and perform hydrologic calculations using these identifiers. The code identification system used in this study was as follows:

Code	Data Type
4	Ground elevation
10	Hydrologic soil groups
11	Land use

(9) One of two codes, -5555 or -6666, precedes the data defining the boundary of a patch. If the -5555 code is used, the patch data will be processed by subsequent programs and inserted into the proper geographic location only where no previously digitized patch partially (or totally) occupies that patch region. If the -6666 code is used, the patch data will be processed by subsequent programs and will replace any data occupying part (or all) of its geographic location.

Topographic Map Digitizing

Topographic Maps

75. A topographic map contains a representation of the areal distribution of ground elevation information. Topographic maps are one example of a broad class of maps representing scalar functions that change value with position on the map. Some data processing procedures for topographic map data differ from the procedures for factor map data because this change in value as a function of position is continuous (change from position to position) rather than discrete as for factor maps.

76. Topographic maps are the normal source of elevation information for hydrologic studies. The elevation data on any contour map can be recovered in a form suitable for computer processing through the use of a digitizer. Just as for factor maps, sufficient information is recorded during the digitizing process to enable subsequent computer calculations to identify the type of data, rectify it, scale and rotate it,

and register it geographically. The same comments in paragraph 74 regarding factor map data are also generally applicable to topographic map data.

77. It is important to remember the conceptual difference between the lines drawn on factor and topographic maps. A line on a factor map bounds a region, every point of which has the same value. A line on a contour map connects all locations with the value of the contour line. A spot elevation on a contour line represents the elevation at that position.

Digitizing Procedure for Topographic Maps

78. Three different sets of information, one of which is not elevation data, must be handled in digitizing the data from a topographic map. The three information sets and the reasons for their use are as follows.

- a. Data Set 1: Area-of-interest boundary. This defines the watershed boundary within which all subsequent data processing operations will take place.
- b. Data Set 2: Contour and spot elevations. These data provide most of the ground elevation information for surface three-dimensional shape and slope trends.
- c. Data Set 3: Waterway channel locations. These define where overland flow terminates and channel flow begins. The waterway locations are also used to provide linear local depressions on the landscape as a refinement of the contour and spot elevation data.

The data are digitized in the order shown above.

79. The digitizing procedure consists of the same two steps used for digitizing factor maps.

- a. Step 1: Positioning the map. A topographic map is positioned on the digitizer table in exactly the same way that a factor map is positioned (see paragraph 74a).
- b. Step 2: Performing the digitizing. Follow the digitizing format for elevation data on contour maps shown in Table 1. The following comments are provided to clarify these steps.
  - (1) The comments numbered (1)-(3) and (5) in paragraph 74c regarding the digitizing of factor maps also apply to the digitizing of topographic maps.
  - (2) The comment (6) in paragraph 74c is also applicable

to the digitizing of topographic maps; an error log form for topographic maps is shown in Figure 5.

(3) When digitizing, the number of points recorded along the boundary line enclosing the area of interest should be only as many as necessary to define the boundary line as a series of straight-line segments as described in the procedure for digitizing factor maps. Note that each area-of-interest boundary is closed and that the computer programs connect the last digitized point with the first for a patch in order to close the boundary. All area-of-interest regions should be digitized before digitizing contour data.

(4) It is almost impossible to memorize what has already been digitized from the map and what remains to be digitized. It is necessary to mark each contour line or spot elevation immediately after it has been digitized. If the map must be protected, a semi-transparent overlay can be placed on the map and marks placed on the overlay.

(5) It is necessary to digitize the data in some pattern, such as left to right or top to bottom on the map, rather than in a random fashion. The computer program to which the digitized data are input has no preference for any pattern or for patterned versus random-distributed data; the person digitizing the data, however, can easily become confused unless some rational pattern is followed. If the map is complex or large, it can be segmented into several sections by drawing irregular-shaped boundaries on the map or overlay. The digitizing pattern can then be followed in each of the map sections.

(6) Spot elevation and contour lines are digitized using exactly the same format. When a spot elevation is digitized, the code -7777 and the spot elevation value are entered into the digitizer, and the single XY-coordinate location of the spot is entered next. When a contour line is digitized, the code -7777 and the contour line elevation are entered into the digitizer followed by a series of X,Y coordinates of points along the contour line. It is permissible to digitize a contour line in pieces, as must be done if the map is sectioned to make the work easier for a complex set of data. If a contour line is digitized in pieces, the stopping location on the line must be noted so the digitizing process can continue on from that location when the next section of the map is digitized.

DIGITIZER OPERATION LOG - ELEVATION MAP DATA

OPERATOR NAME:______________________________ DATE:___________ TIME:__________

DIGITIZER TYPE AND LOCATION:____

AREA-OF-INTEREST PATCH	COMMENTS

ELEVATION	COMMENTS

Stream Segment	COMMENTS

Figure 5. Error log form for topographic maps

(7) Supplementary elevation data should be added to the contour map to increase the quality of the product. Closed contours indicate the presence of a ridge, trough, saddle, or hilltop. The approximate elevations and locations of these features can be estimated from the available data on the map, and the ridge and trough lines and peak and pit point data entered into the digitizer just as the contour and spot elevation data.

(8) The pattern of streamflow center lines should be traced on the contour map or on a transparent overlay. The streamflow pattern consists of all flow channels visible on the base map or obvious from the contour line pattern. The reason for locating the streamflow pattern in the elevation data is to provide information as to the local minimum elevations.

(9) A streamflow pattern is made up of a series of channels or segments linked together like branches on a tree. Data for each of the segments should be digitized following the procedure on the digitizing format under the heading "The following data are digitized from the photo and contour maps." The order in which the stream segments are digitized is unimportant. Frequently, the stream locations are not readily distinguishable on the base map. When in doubt, always use the contour line pattern to indicate the stream location.

(10) As noted in the digitizing format, the area-of-interest and contour map data consist of one code record followed by a series of X,Y coordinates, while the streamflow data for any stream segment consist of a series of X,Y coordinates that are preceded and followed by code records and also can have code records imbedded in it.

(11) The starting and ending code records for a stream segment are entered into the digitizer for the start and end of a stream segment. The code records imbedded in a stream segment's data are for all locations where contour lines intersect the segment. It is possible for a stream segment to start or end on a contour line. If the grade is steep, many contour lines may intersect the segment; if the grade is slow, few or no contour lines may intersect the segment. The elevations at the beginning and ends of the stream segment should be estimated from the available contour line pattern. If the segment starts or ends on a contour line, the elevation of

that line should be used. The X,Y coordinates digitized along the segment should have a spacing approximately equal to the distance to the nearer neighboring contour line.

Variations in Digitizing

80. The described procedures for factor and topographic map digitizing contain the basic information required to perform the work. There are several variations in the digitizing procedure that can be used to reduce both the digitizing effort and potential data problems. These variations are beyond the scope of this report but are available from the author.

Data Preparation Overview

81. Data preparation involves progression through several work levels, starting with the preparation of materials containing the data and ending with the data basing of processed data as shown below. All data used in the calculations pass through one or more of these work levels.

a. Level A: Material preparation.

b. Level B: Data recovery.

c. Level C: Data preprocessing.

d. Level D: Data processing.

e. Level E: Data basing.

Figure 6 shows in detail the operations that must be performed, the work level of each, and the relative scheduling of the work. The sequential ordering of the operations shown by the arrows in Figure 6 indicates the relative time scheduling of the operations. (The sizes of the blocks in Figure 6 have no significance as to work effort or time.) If time-scheduling blocks for two operations overlap, they can be performed at the same time; if they do not overlap, they must be performed in the indicated sequence. Solid lines with arrows are used to indicate the flow of work on a given data set as it passes through subsequent

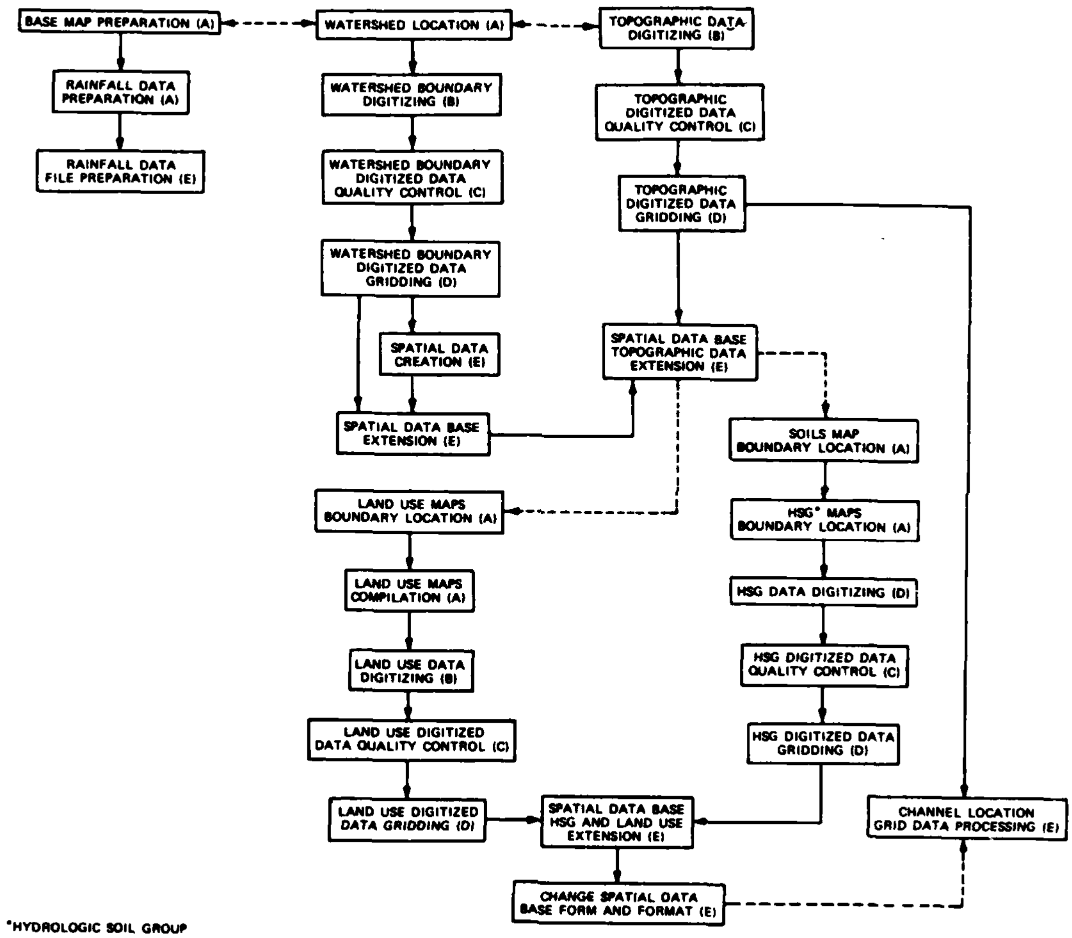


Figure 6. Data preparation overview

operations. Dashed lines with arrows indicate that the results of the operation at the tail of the dashed line are used indirectly in the operation at the head. Finally, the work level of each operation (A-E as listed above) is indicated in parentheses following the name for each work operation.

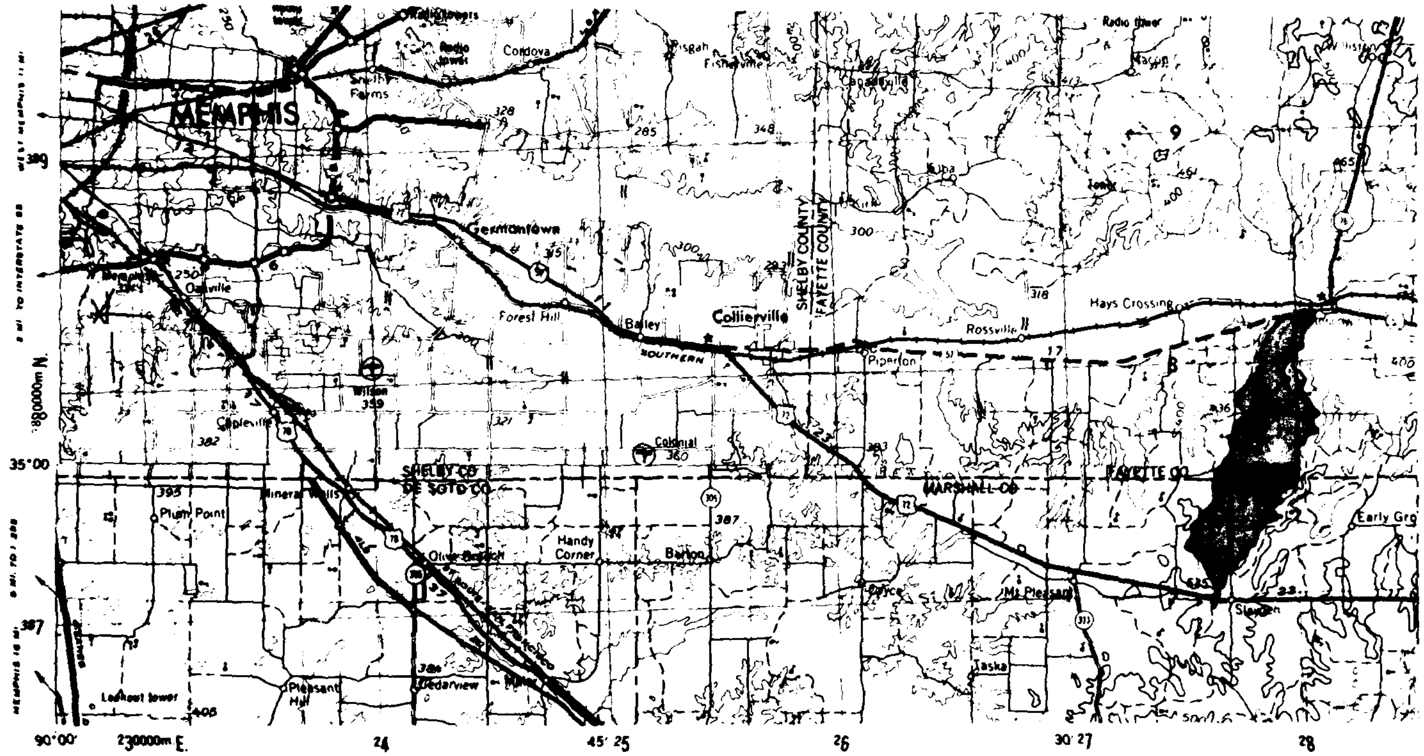
82. Figure 6 was prepared with an assumption that the required data would be available from certain standard, normally used sources and that the data would be available in the normal form and format. For example, it was assumed that elevation data would be available on topographic maps whether the maps were printed by the USGS or prepared by the Corps for a planning study. It is possible for Figure 6 to be configured in several other forms.

83. Succeeding sections of this report describe the data preparation operations in detail.

84. All data preparation operations culminate in the preparation of digital computerized data files that are used in calculations (see Figure 1). A discussion of the calculation operations is provided in Part IV of this report.

Study Watershed

85. The study watershed, Golden Creek, is a tributary of the Wolf River. Its location is shown in the computer-plotted overlay to the 1:250,000-scale USGS topographic maps N1 16-1, Blytheville, and N1 16-4, Tupelo, in Figure 7. The headwaters of Golden Creek arise in northern Mississippi and flow north into Tennessee to a confluence with the Wolf River. The Wolf River flows generally westward from the confluence and empties into the Mississippi River at Memphis, Tennessee. The watershed location is shown only for location reference; these data are not used in the study. The computer-plotted overlay was produced from the spatial data base at the appropriate scale for overlaying the 1:250,000-scale topographic map.



V501, EDITION 3

Prepared by the U.S. Army Topographic Command (TVSX), Washington, D.C. Compiled in 1956 by photogrammetric methods and from United States quadrangles 1:24,000, 1:25,000, 1:50,000, and 1:62,500, 1921-55. *Planimetry revised in part from aerial photographs taken 1953. Map field checked 1956.* Revised by the U.S. Geological Survey 1970.

LEGEND

POPULATED PLACES
Over 500,000 — BOSTON
100,000 to 500,000 — RICHMOND
25,000 to 100,000 — EVANSTON
5,000 to 25,000 — Hialeah

ROADS
Primary, all weather, hard surface
Secondary, all-weather, hard surface
Light-duty, all weather, hard or improved surface
Fair or dry weather, unimproved surface
Trail

Scale 1:250,000

Figure 7. Study watershed location

Base Maps

86. The base maps used in this study consisted of 1:12,000-scale aerial photograph maps, with topographic map overlays of the same scale prepared for planning studies. The topographic maps consisted of contour plates for USGS 1:24,500-scale topographic maps photographically expanded to a scale of 1:12,000. Black-and-white aerial photographs at a scale of 1:12,000 were mosaicked onto the photographically expanded contour plates to provide the aerial photograph maps.

87. It was necessary to butt together five base maps to achieve coverage of the total watershed. (Figure 8 shows an index of those base maps.) An indication of the physical size of each base map is given in the pictures shown in Figure 9, in which the photomap and the topographic map overlay for index map 3 are displayed. The developed data processing procedures are independent of the maps' physical size or scale.

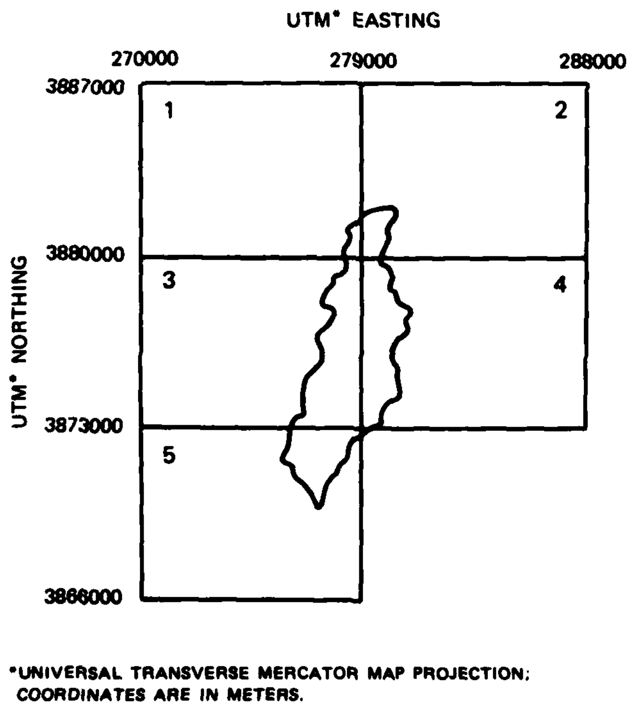


Figure 8. Base map index

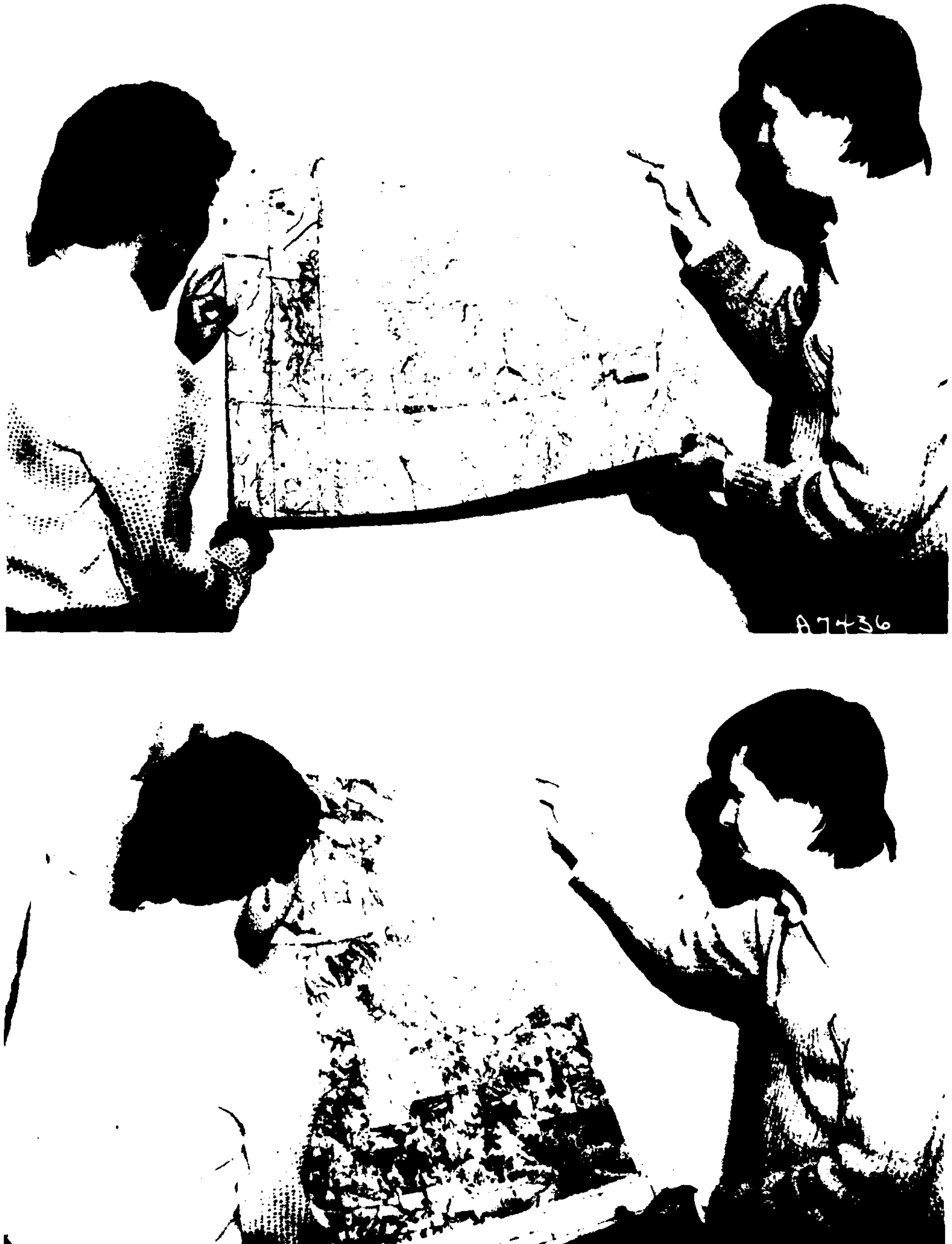


Figure 9. Photomap (top) and topographic map for base map 3

Watershed Boundary

88. The watershed boundary was delineated on the base maps manually by interpreting the watershed dividing line from the permanent and intermittent channels of the stream and the contour lines shown on the contour plates. The watershed region on each base map was digitized and the digitized data processed following the schedule shown in Figure 10.

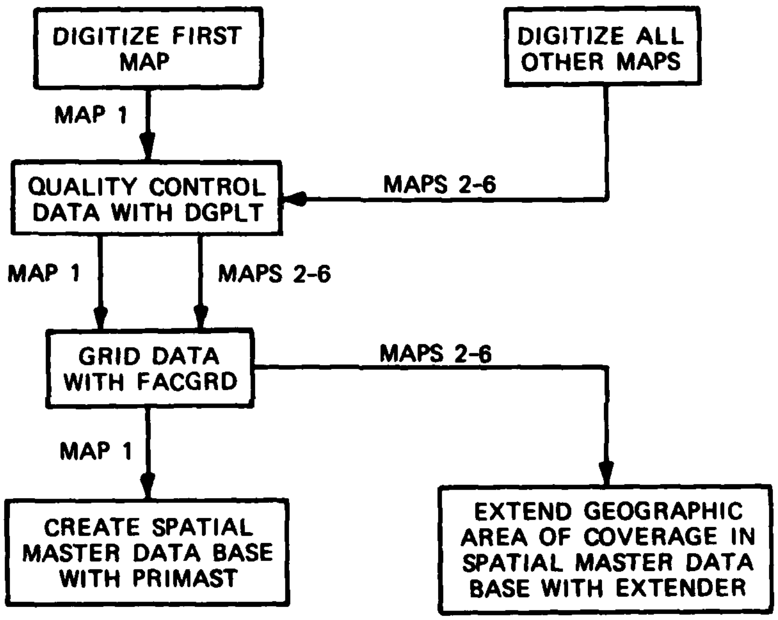


Figure 10. Schedule for processing watershed boundary data

(Note that Figure 8 shows the portion of the watershed on each of the base maps in this study.) The watershed boundary data must be processed first to provide a definition of the geographic area for which data will be retained in the master data base. The reader should note that the watershed boundary maps are the simplest maps to be processed; examples of data used in processing other types of factor maps are shown in Figures 11-13 to demonstrate the factor map processing procedure.

89. As shown in Figure 10, the first digitized map provides data used to create the spatial master data base; all other digitized maps are used to extend the geographic area of coverage of the spatial master

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-------------------------------------------------------------
-------------------------------------------------------------
-------------------------------------------------------------
     THE FOLLOWING INPUT DATA USED FOR IDENTIFICATION AND
SPATIAL PLACEMENT OF THE DATA FILE CONTENTS SHOULD BE CHECKED
-------------------------------------------------------------

THE X AND Y SCALE FACTORS USED IN PLOTTING THE MAP ARE    0.01000    0.01000
    INPUT DATA                      DESCRIPTION
 -------------  ---------------------------------------------


      4       11   FILE IDENTIFICATION NUMBER AND DATA TYPE CODE
    279     3880   UTM COORDINATES FOR THE UPPER LEFT MAP CORNER
    282     3873   UTM COORDINATES FOR THE LOWER RIGHT MAP CORNER
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THE FOLLOWING LEGEND SHOULD BE REVIEWED FOR POSSIBLE ERRORS IN THE INPUT DATA.
THE LEGEND CONTAINS ALL CODE RECORDS FOUND IN THE INPUT DATA, AND THE NUMBER PLOTTED ON
THE MAP I PRODUCED SHOWING THE DATA ASSOCIATED WITH EACH CODE RECORD.
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```

LEGEND FOR INPUT FILE
SHOWING ALL CODES IN FILE

RECORD NUMBER	CODE	VALUE	NO. DATA POINTS	MAP SYMBOL
10008	-5555	-999	38	1
10047	-6666	1	39	2
10087	-6666	9	48	3
10136	-6666	12	52	4
10189	-6666	12	11	5
10201	-6666	12	13	6
10215	-6666	12	68	7
10284	-6666	1	4	8
10289	-6666	1	7	9
10297	-6666	6	9	10
10307	-6666	12	111	11
10419	-6666	9	15	12
10435	-6666	9	217	13
10653	-6666	9	6	14
10660	-6666	6	4	15
10665	-6666	9	35	16
10701	-6666	1	4	17
10706	-6666	12	27	18
10734	-6666	9	31	19
10766	-6666	9	23	20
10790	-6666	9	154	21
10945	-6666	6	6	22
10952	-6666	1	23	23

Figure 11. Sample tabular output from DGPLT for a land use factor map

Figure 12. Sample computer plot of a factor map from DGPLT

FACGRD PROGRAM OPERATION REPORT

UTM CORNER COORDINATES AS INPUT
279000 3890000 292000 3973000

OUTPUT TAPE INFORMATION SECTION

11 279000 3890000 282000 3973000
GOLDEN CREEK STUDY
GRID SPACING-100.0 M

MAP NO. 4 LU
JUNE 4, 1982

1.00 31 71 100.0

THE FOLLOWING IS A RECORD OF THE INPUT FILE DATA SETS HANDLED IN THE GRIDDING TRANSFORMATION

INPUT DIGITIZED DATA					OUTPUT GRIDDED PATCHES					
					LOCATION,GRIDS					
					MIN		MAX			
NO.	START LINE	CODE	VALUE	NUMBER POINTS	X	Y	X	Y	AREA, GRIDS	COMMENTS
1	10008	-5555	-999	34	13	1	31	72	931	THIS PATCH EXTENDS OUTSIDE THE MAP BOTTOM BOUNDARY
2	10047	-6666	1	39	0	1	23	72	1299	THIS PATCH EXTENDS OUTSIDE THE MAP LEFT BOUNDARY THIS PATCH EXTENDS OUTSIDE THE MAP BOTTOM BOUNDARY
3	10087	-6666	9	48	2	69	9	72	10	THIS PATCH EXTENDS OUTSIDE THE MAP BOTTOM BOUNDARY
4	10136	-6666	12	52	0	66	8	72	24	I SUSPECT THAT SOMETHING'S WRONG WITH THIS DATA SUBSET THIS PATCH EXTENDS OUTSIDE THE MAP LEFT BOUNDARY THIS PATCH EXTENDS OUTSIDE THE MAP BOTTOM BOUNDARY
5	10189	-6666	12	11	0	66	4	68	5	THIS PATCH EXTENDS OUTSIDE THE MAP LEFT BOUNDARY
6	10201	-6666	12	13	0	64	3	67	5	THIS PATCH EXTENDS OUTSIDE THE MAP LEFT BOUNDARY
7	10215	-6666	12	69	0	55	7	66	42	THIS PATCH EXTENDS OUTSIDE THE MAP LEFT BOUNDARY
8	10284	-6666	1	4	1	59	2	60	1	
9	10289	-6666	1	7	2	57	2	59	0	THIS PATCH IS TOO SMALL OR ORIENTED IN SUCH A WAY AS TO NOT APPEAR IN THIS OUTPUT ARRAY
10	10297	-6666	6	9	0	57	2	59	2	THIS PATCH EXTENDS OUTSIDE THE MAP LEFT BOUNDARY
11	10307	-6666	12	111	0	51	11	62	39	THIS PATCH EXTENDS OUTSIDE THE MAP LEFT BOUNDARY
12	10419	-6666	9	15	2	53	5	55	1	

a. Report on input data

PATCH DATA OUTPUT TO MAGNETIC TAPE

			LOCATION,GRIDS			
			MIN		MAX	
INPUT SEQUENCE NUMBER	VALUE	AREA GRIDS	X	Y	X	Y
-NA-	0	0	9999	9999	-9999	-9999
1	-999	898	12	1	31	71
2	1	680	1	1	23	71
3	9	8	4	69	8	71
4	12	24	1	67	8	71
5	12	5	1	66	3	67
6	12	5	1	64	3	66
7	12	40	1	55	7	65
8	1	1	2	59	2	59
9	1	0	9999	9999	-9999	-9999
10	6	2	1	57	2	58
11	12	38	1	51	11	61
12	9	1	5	54	5	54
13	9	53	1	34	13	49
14	9	3	5	44	6	45
15	6	0	9999	9999	-9999	-9999
16	9	6	2	39	5	41
17	1	1	4	40	4	40
18	12	6	1	38	3	40
19	9	10	1	28	3	33
20	9	6	1	24	2	27
21	9	27	2	16	14	26
22	6	2	1	21	1	22
23	1	21	2	20	8	24
24	12	52	8	60	17	69
25	12	3	13	57	15	57
26	9	6	16	55	18	57
27	12	20	15	47	19	54
28	9	3	16	52	18	54
29	12	13	9	49	13	53
30	12	7	15	43	17	46
31	9	2	12	43	13	43
32	9	51	13	30	22	44
33	9	1	15	36	15	36
34	9	0	9999	9999	-9999	-9999
35	9	1	9	35	9	35
36	12	0	9999	9999	-9999	-9999
37	9	6	17	27	18	31
38	9	1	23	28	23	28
39	9	19	19	23	23	28

b. Basic patch parameters

Figure 13. Sample tabular output report of FACGRD

```
       0   0   0   0   0   0   0   0   0   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   3   3
       1   2   3   4   5   6   7   8   9   0   1   2   3   4   5   6   7   8   9   0   1   2   3   4   5   6   7   8   9   0   1
     --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- ---
  1/   1   1   1   1   9   9   9   1   9   9   9   1-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  2/   1   1   9   1   9   9   9   1   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  3/   1   1   1   1   9   9   1   9   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  4/   1   1   1   1   9   9   1   9   9   9   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  5/   1   1   1   1   1   1   1   1   1   9   1   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  6/   1   1   1   1   1   1   1   1   1   1   1   9   9   9   1   1-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  7/   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1-999-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  8/   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1-999-999-999-999-999-999-999-999-999-999-999-999-999-999
  9/   1   9   9   1   1   1   1   1   1   1   1   1   1   1   1   1   9-999-999-999-999-999-999-999-999-999-999-999-999-999-999
 10/   1   9   1   1   1   9   1   1   1   1   1   1   1   1   1   1   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999
 11/   1   9   9   9   1   1   9   1   1   1   1   1   1   1   1   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999
 12/   1   9   9   9   9   1   1   1   1   1   1   1   1   1   1   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999
 13/   1   9   9   9   9   9   9   1   1   1   1   1   1   1   9   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999
 14/   1   9   1   9   9   9   1   1   1   1   1   1   1   1   1   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999
 15/   1   9   9   1   1   9   9   1   1   1   1   1   1   1   1   9   9   9   9   1-999-999-999-999-999-999-999-999-999-999-999
 16/   9   9   9   1   1   1   9   9   1   1   1   1   1   1   1   9   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999
 17/   1   9   1   1   1   1   9   1   1   1   1   9   1   1   1   1   1   9   1   9   9-999-999-999-999-999-999-999-999-999-999
 18/   1   9   1   9   1   1   1   9   1   9   9   9   9   1   1   1   9   9   1   9   9   9-999-999-999-999-999-999-999-999-999
 19/   1   9   1   1   1   1   9   9   1   1   9   9   9   9   1   1   1   1   1   1   1   9-999-999-999-999-999-999-999-999-999
 20/   1   9   9   9   1   1   1   9   9   9   9   9   9   9   1   1   9   1   1   1   1   9   9-999-999-999-999-999-999-999-999
 21/   6   1   1   1   1   1   1   9   1   1   9   1   1   1   1   1   9   9   1   1   9   9   9-999-999-999-999-999-999-999-999
 22/   6   9   1   1   1   1   1   9   1   1   1   1   1   1   1   1   9   9   9   1   1   1   1-999-999-999-999-999-999-999-999
 23/   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   9   9   1   1   9   9   1-999-999-999-999-999-999-999-999
 24/   1   9   9   1   1   1   1   1   9   1   1   1   1   1   1   1   9   1   1   9   9   9   9-999-999-999-999-999-999-999-999
 25/   9   9   9  12  12  12   1   1   9   1   1   1   1   1   1   1   9   9   9   9   9   9   9-999-999-999-999-999-999-999-999
 26/   9   1   9  12  12   1   1  12   9   1   1   1   1   1   1   1   1   1   9   1   9   9   9-999-999-999-999-999-999-999-999
 27/   9   9   1   1  12  12  12  12   9   1   1   1   1   1   1   1   9   1   9   9   9   1   1-999-999-999-999-999-999-999-999
 28/   1   1   9   1   1  12  12   9   9   1   1   1   1   1   1   1   9   1   1   9   1   1   9-999-999-999-999-999-999-999-999
 29/   9   9   1  12  12  12   1   1   9   1   1   1   1   1   1   1   9   9   1   1   1   1   1-999-999-999-999-999-999-999-999
 30/   9   9   1  12  12  12   9   9   1   1   1   1   1   1   1   1   1   9   1   9   1   1-999-999-999-999-999-999-999-999-999
 31/   9   1   1   1   1   1   9   9   1   9   9   1   1   1   1   1   1   9   1   9   9   1-999-999-999-999-999-999-999-999-999
 32/   9   9   9   1   1   9   9   9   1   9   9   9   9   1   1   1   1   1   9   9   9   1-999-999-999-999-999-999-999-999-999
 33/   1   9   1   1   1   1   9   9   1   9   9   9   9   1   1   1   1   1   9   9   9   1-999-999-999-999-999-999-999-999-999
 34/   1   1   1   1   9   1   1   9   1   1   9   9   9   1   1   1   1   1   1   1   9   9-999-999-999-999-999-999-999-999-999
 35/   1   1   1   9   1   9   1   1   9   1   9   9   1   1   1   9   9   9   9   9   9   9-999-999-999-999-999-999-999-999-999
 36/   1   1   1   1   9   9   1   1   1   1   1   1   1   1   9   9   9   9   9   9   9-999-999-999-999-999-999-999-999-999-999
 37/   1   1   1   1   9   9   1   1   9   9   1   1   1   1   1   9   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999
 38/  12   1  12   1   1   1   9   9   9   9   9   9   1   1   9   9   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999
 39/  12  12   9   1   1   1   9   9   9   9   1   1   1   1   9   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999
 40/  12  12   9   1   1   1   9   1   1   1   1   9   9   1   1   9   1   1-999-999-999-999-999-999-999-999-999-999-999-999-999
 41/   1   9   9   9   9   1   9   9   9   1   1   1   9   9   9   9   1-999-999-999-999-999-999-999-999-999-999-999-999-999-999
 42/   1   1   1   1   1   1   1   9   1   1   1   1   1   9   9   9   1-999-999-999-999-999-999-999-999-999-999-999-999-999-999
 43/   9   9   1   1   1   1   1   9   9   9   1   9   9   9   9   9  12-999-999-999-999-999-999-999-999-999-999-999-999-999-999
 44/   1   1   1   1   9   9   1   9   1   1   1   1   1   1   9   1  12-999-999-999-999-999-999-999-999-999-999-999-999-999-999
 45/   1   9   9   1   1   9   9   9   9   1   9   9   1   1  12  12  12-999-999-999-999-999-999-999-999-999-999-999-999-999-999
 46/   1   1   9   9   1   1   1   9   9   9   9   1   1   1  12  12   1   1-999-999-999-999-999-999-999-999-999-999-999-999-999
 47/   1   1   1   9   1   1   1   9   1   9   9   1   1   1   1   1  12  12  12-999-999-999-999-999-999-999-999-999-999-999-999
 48/   1   1   1   1   1   1   1   9   1   1   1   9   9   1   1   1  12  12  12-999-999-999-999-999-999-999-999-999-999-999-999
 49/   1   1   1   1   9   1   1   1   1  12  12  12  12   1   1   1   1  12  12   1-999-999-999-999-999-999-999-999-999-999-999
 50/   1   1   1   1   1   1   1   1  12  12  12  12   1   1   1   1   1   1  12   1-999-999-999-999-999-999-999-999-999-999-999
 51/   1   1   1  12  12   1   1   1   1   1  12  12   1   1   1   1   1   1  12-999-999-999-999-999-999-999-999-999-999-999-999
 52/   1   1  12  12   1   1   1   1   1   1  12  12   1   1   1   9  12  12  12-999-999-999-999-999-999-999-999-999-999-999-999
 53/  12  12  12  12   1   1  12  12  12   1   1  12   1   1  12  12   9  12  12-999-999-999-999-999-999-999-999-999-999-999-999
 54/  12   1   1  12   9  12  12  12  12   1   1   1   1   1  12  12  12   9-999-999-999-999-999-999-999-999-999-999-999-999-999
 55/  12   1   1  12  12  12  12   1   1   1   1   1   1   1   1   9   9   9-999-999-999-999-999-999-999-999-999-999-999-999-999
```

c. Sample grid map

Figure 13. (Concluded)

data base. The data from all maps is placed in the information system. Figure 10 indicates that the first digitized map is map number 1; the first digitized map could be any of the maps.

90. All digitized map data are reviewed for quality control using the program DGPLT. DGPLT performs the following functions.

a. It checks the format and layout of the data to ensure that the digitizing rules were followed and that the data will be acceptable to the program that transforms the boundary line coordinates into the grid coordinate system.

b. DGPLT also provides a tabular output that summarizes all input data in an abbreviated form so the user can check data values that DGPLT is not capable of checking automatically. Figure 11 shows a sample tabular output for the first part of a land use map. (A land use map was used for an example since watershed boundary maps, containing one line per map (see Figure 8), are almost featureless.) No errors were encountered in the data, so error comments were not provided. An inspection of the code data (last item in Figure 11) shows that the data were from a factor map (codes -5555 and -6666). The "No. Data Points" column shows the number of digitized data points on each factor map patch boundary. The "Map Symbol" number is the sequentially ordered number assigned by DGPLT to each set of data; these are the numbers plotted on the map overlay for identification purposes. The "Record Number" information is the record number in the computer file where data for each factor map patch starts, so that erroneous data can be easily located if necessary.

c. Finally, DGPLT produces a computer plot that is an exact overlay of the original map data that were digitized. A portion of a reduced sample of such a computer plot is shown in Figure 12. The computer plot is intended for overlay on the original to provide a visual check of the accuracy of the digitized patch boundary line layout. As noted in the previous paragraph, the numbers plotted on the maps are keyed back to the original digital data through the map symbol and record number in the tabular output such as that shown in Figure 11.

d. DGPLT does not process the data; that is, DGPLT does not produce an output file.

91. The watershed boundary data input to DGPLT are input to program FACGRD after the tabular report and map produced by DGPLT have been checked. The program FACGRD performs the following functions:

a. It checks the form and format of the input digitized data. FACGRD also transforms the data from the coordinate system in which they were digitized into a grid coordinate system in state planar or Universal Transverse Mercator (UTM) coordinate space. Data for the study watershed were transformed into the UTM system. FACGRD also scales, rotates, and rectifies the input digitized data while performing the coordinate transformation. As the transformation is taking place, the program fills the region in the grid array delineated by each patch boundary with the value assigned to the patch. A grid is included within a patch if more than half of the grid lies within the patch.

b. FACGRD also produces a tabular output that synopsizes the calculation and details any definite or possible problems encounted in the calculation. A sample tabular output is shown in Figure 13. The top section of Figure 13a is self-explanatory; the latter half of the figure contains the information that is of primary interest for review. The "Input Digitized Data" number is a sequential number assigned to data sets and is identical to the map symbol number of Figure 11. The "Start Line" data show the record line number identifiers of the data sets, so any individual data set can be easily located in the input data file. The "Code" and "Value" numbers show the code system used for each patch boundary during digitizing and the value to be placed within each patch. The "Min" and "Max" grid locations and the area data show the maximum and minimum bounding XY-grid coordinates of each input patch and the patch area in grids as each patch is processed. The "Comments" column provides a place for FACGRD to inform the user as to special situations, possible problems, and definite errors it encounters in processing the data set for each patch. Figure 13b shows an example of the basic patch parameter report for patch data set input to and processed by FACGRD after processing of all patches. This report gives the value, area, and bounding XY-grid coordinates for every patch, which changes from the values shown in 13a since patches overlap or form islands within other patches. The code 9999 appears when an input patch was deleted (i.e., does not appear in the output file) (for example, see patch number 9 in Figure 13a and b). Figure 13c shows an example of the data grid map provided by FACGRD, demonstrating the contents of the output file. The -999 code is used to designate the area outside the watershed. Specific patches in 13b can be located in the grid maps. For example, patch number 18 in Figure 12b can be located in Figure 12c by noting the minimum-maximum grid coordinate location and value of the patch in 13b. This output

report is used as follows: The user scans the comments column in Figure 13a for patches that should be checked, finds the patch location in Figure 13a, and visually compares the patch in Figure 13c with the original digitized map.

c. Finally, as previously indicated, FACGRD outputs the results of the grid calculation to a computer file. The output contains all geographic location, size, and grid spacing information in addition to the grid data. Figure 13c is an example of the gridded data portion of this file, and Figure 8 is a sample computer plot of the gridded data file showing the geographic extent of the study area after all maps for the study watershed were processed.

92. The spatial master data base is created using the first watershed boundary gridded data output from program FACGRD. The computer program that performs this function is called PRIMAST. Program PRIMAST sets up a data file containing the X,Y coordinates of all grids within the watershed shown on that first input map. All other watershed boundary grid arrays output from FACGRD are processed through the program EXTENDER to provide the total spatial master data base geographic layout. The order in which the grid arrays are processed by EXTENDER is unimportant since the geographic location data included in each grid file are used for spatial location of the data in the master data base.

93. At the completion of the EXTENDER operations, the spatial master data base contains XY-coordinate information for all grids that lie within the watershed boundary. This concludes the use of the watershed boundary data.

Topography

94. The source of topographic information used in this study was the contour information on the contour plate overlays to the base map and the stream channel locations on the photo maps. These data were digitized following the rules in Table 3 and processed using the following schedule:

Digitize each map

↓

Quality control data with DGPLT

↓

Grid data with MGRIDDER

↓

Add data to spatial master data base with GROW

95. Prior to digitizing each map, the watershed boundary was extended on each map to delineate a slightly larger region. Elevation data digitized from each base map included all data within the watershed boundary line drawn on the map and also this band outside the boundary. This extra band of data was digitized to negate edge effects in the grid calculation and to ensure that the elevation grid data would cover the total watershed area. Wherever base maps butted, a band of data outside the boundary of each map was supplied from the data on the butting map.

96. All digitized data were quality controlled using program DGPLT, which was described in paragraph 90. The tabular and graphic outputs of DGPLT have a slightly different appearance when processing topographic data than when processing factor map data. Figure 14 shows a sample tabular output which contains a summary of all input data and information needed by the user to review the data quality and rapidly locate any problems. Figure 15 is a reduced copy of part of a computer-plotted overlay produced by DGPLT.

97. The same digitized topographic data input to DGPLT are input to the program MGRIDDER after checking the output tabular and graphic results from DGPLT. The program MGRIDDER provides the following processing functions. It checks the form and format of the input digitized data to ensure that they are rigorously correct. It transforms the data from the coordinate system in which they were digitized into a grid coordinate system in state planar or UTM coordinate space. MGRIDDER also rectifies the data while performing the coordinate transformation, and calculates a three-dimensional ground elevation surface using the input

```
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-------------------------------------------------------------
     THE FOLLOWING INPUT DATA USED FOR IDENTIFICATION AND
SPATIAL PLACEMENT OF THE DATA FILE CONTENTS SHOULD BE CHECKED
-------------------------------------------------------------

THE X AND Y SCALE FACTORS USED IN PLOTTING THE MAP ARE   0.00100   0.00100
   INPUT DATA                         DESCRIPTION
 -------------  -------------------------------------------


     4          4  FILE IDENTIFICATION NUMBER AND DATA TYPE CODE
   279       3980  UTM COORDINATES FOR THE UPPER LEFT MAP CORNER
   281       3973  UTM COORDINATES FOR THE LOWER RIGHT MAP CORNER
-------------------------------------------------------------


-------------------------------------------------------------------------------------
THE FOLLOWING LEGEND SHOULD BE REVIEWED FOR POSSIBLE ERRORS IN THE INPUT DATA.
THE LEGEND CONTAINS ALL CODE RECORDS FOUND IN THE INPUT DATA, AND THE NUMBER PLOTTED ON
THE MAP I PRODUCED SHOWING THE DATA ASSOCIATED WITH EACH CODE RECORD.
-------------------------------------------------------------------------------------
```

LEGEND FOR INPUT FILE
SHOWING ALL CODES IN FILE

RECORD NUMBER	CODE	VALUE	NO. DATA POINTS	MAP SYMBOL
10005	-5555	0	189	1
10195	-7777	360	41	2
10240	-7777	360	7	3
10243	-7777	370	143	4
10392	-7777	380	189	5
10532	-7777	390	433	6
11016	-7777	390	56	7
11073	-7777	400	520	8
11694	-7777	410	642	9
12337	-7777	405	29	10
12367	-7777	400	9	11
12375	-7777	405	7	12
12384	-7777	400	7	13
12392	-7777	390	4	14
12397	-7777	420	768	15
13166	-7777	415	16	16
13153	-7777	430	13	17
13197	-7777	430	9	18
13207	-7777	430	717	19
13925	-7777	425	11	20
13937	-7777	425	5	21
13943	-7777	425	5	22
13947	-7777	425	6	23

Figure 14. Sample tabular output from DGPLT for a topographic map

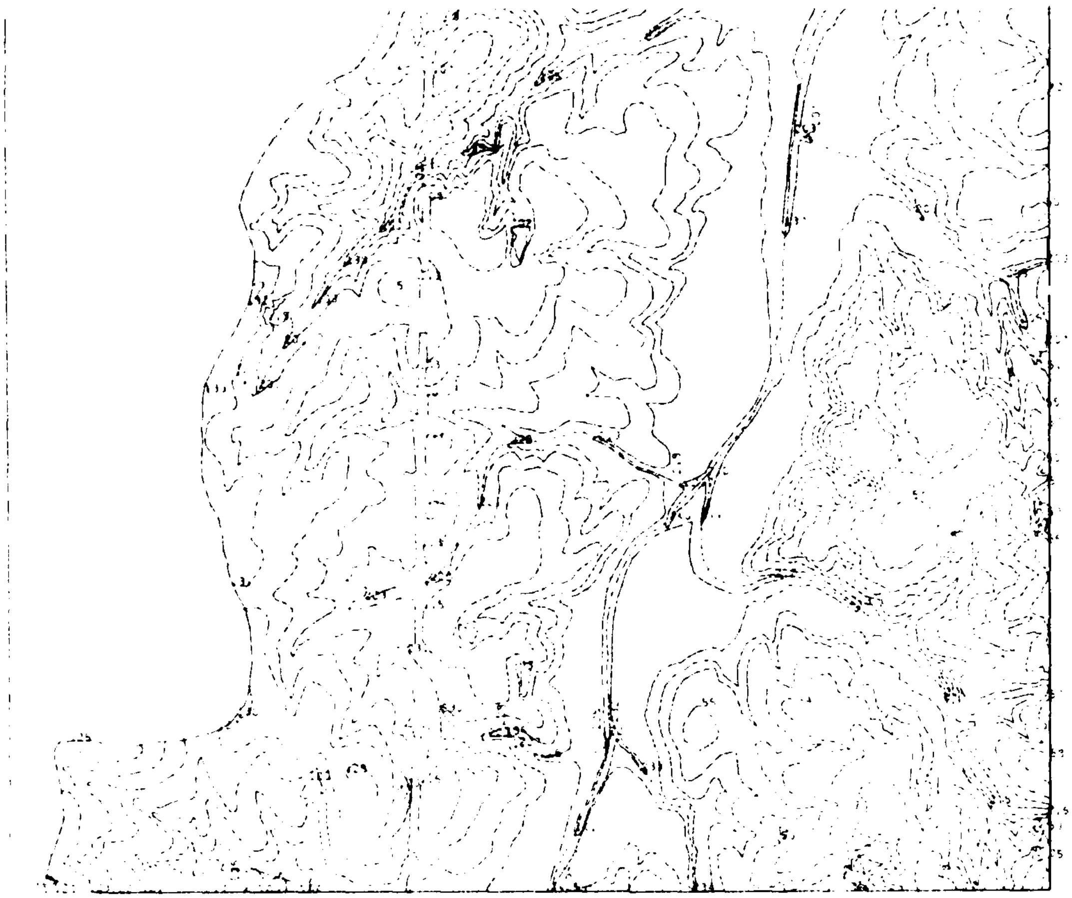


Figure 15. Sample computer plot of a topographic map from DGPLT

data. The calculation is performed for all grid locations for which input data are not available and involves the selection and use of one interpolative or extrapolative algorithm from a library of several choices based on the configuration of digitized data in the locale where the grid calculation is being performed. Finally, MGRIDDER provides a tabular output that synopsizes the calculation and provides information regarding any problems encountered in the calculation. A sample tabular output is shown in Figure 16. The Figure 16a contains a typical operation report from the program. Most of the information is self-explanatory. There was an area of interest that defined the geographic area of the calculation (-5555 code data). The data were

```
ELEVGRD PROGRAM OPERATION REPORT
----------------------------------------------------
UTM CORNER COORDINATES AS INPUT
   279000   3880000   281000   3873000
----------------------------------------------------

OUTPUT TAPE INFORMATION SECTION
----------------------------------------------------
        4   279000   3880000   281000   3873000
MGRIDDER
GOLDEN CREEK
GRID SPACING-100 M.
JUNE 9, 1982

0.03          21     71 100.0
----------------------------------------------------

THE FOLLOWING IS A RECORD OF THE OUTPUT FILE DATA
 SETS HANDLED IN THE VARIABLE SURFACE CALCULATION
----------------------------------------------------
              INPUT DIGITIZED DATA
         -----------------------------------
            START                    NUMBER
     NO.    LINE    CODE    VALUE    POINTS
     ---   ------  ------  ------   ------
       1    10009   -5555       0      190

ORIGINAL NUMBER OF HOLES IN THE N ARRAY =        12

THE FOLLOWING COORDINATE PAIRS LOCATE
THE REMAINING EMPTY GRIDS
   I      J
-----  -----

FINAL NUMBER OF HOLES IN THE N ARRAY =         0
```

3600	3613	3750	3936	4022	4153	4263	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
3630	3600	3686	3859	4206	4140	4235	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
3600	3600	3641	3789	3991	4146	4238	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
3608	3606	3637	3791	3997	4150	4236	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
3631	3634	3652	3793	3973	4165	4306	4348	4374	4422	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
3657	3674	3704	3794	3957	4168	4322	4377	4418	4500	4583	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
3679	3704	3744	3820	3954	4104	4207	4285	4385	4517	4625	4675	-999	-999	-999	-999	-999	-999	-999	-999	-999
3686	3715	3778	3854	3952	4047	4131	4243	4398	4551	4636	4678	-999	-999	-999	-999	-999	-999	-999	-999	-999
3700	3715	3805	3887	3928	3968	4034	4176	4363	4490	4558	4623	4672	-999	-999	-999	-999	-999	-999	-999	-999
3738	3719	3794	3847	3839	3866	3931	4053	4221	4355	4488	4607	4653	-999	-999	-999	-999	-999	-999	-999	-999
3791	3743	3727	3753	3798	3870	3950	4029	4147	4325	4512	4633	-999	-999	-999	-999	-999	-999	-999	-999	-999
3846	3830	3771	3819	3915	3981	4055	4126	4212	4379	4549	4633	-999	-999	-999	-999	-999	-999	-999	-999	-999
3858	3912	3930	4007	4107	4184	4243	4287	4325	4417	4533	4581	-999	-999	-999	-999	-999	-999	-999	-999	-999
3869	3946	4024	4112	4255	4400	4435	4431	4437	4447	4479	4510	4528	-999	-999	-999	-999	-999	-999	-999	-999
3914	3983	4074	4175	4317	4459	4485	4487	4483	4430	4402	4440	4486	-999	-999	-999	-999	-999	-999	-999	-999
3999	4074	4127	4229	4331	4372	4379	4428	4424	4348	4313	4375	4452	-999	-999	-999	-999	-999	-999	-999	-999
4037	4145	4137	4190	4289	4284	4251	4309	4308	4244	4264	4362	4431	-999	-999	-999	-999	-999	-999	-999	-999
3959	4103	4091	4099	4198	4206	4164	4198	4191	4157	4234	4333	4374	4410	-999	-999	-999	-999	-999	-999	-999
3956	4031	3992	3971	4018	4025	4018	4058	4080	4085	4144	4226	4299	4370	4416	-999	-999	-999	-999	-999	-999
3847	3904	3898	3843	3849	3859	3868	3902	3958	4003	4062	4151	4244	4329	4382	4400	4430	-999	-999	-999	-999
3762	3769	3790	3816	3842	3864	3863	3854	3901	3953	4010	4098	4194	4275	4321	4374	4432	4475	4483	-999	-999
3852	3814	3803	3867	3906	3913	3888	3892	4001	4037	3981	4006	4114	4207	4261	4334	4413	4456	4522	-999	-999
4000	3955	3930	3945	3994	3971	3894	3920	4107	4165	4008	3982	4048	4116	4193	4291	4385	4445	4517	4351	-999
4148	4099	3996	3982	4045	4075	3994	3930	4051	4136	4067	4062	4095	4096	4158	4266	4371	4449	4497	-999	-999
4254	4218	4098	4023	4093	4185	4110	3938	3951	4097	4135	4140	4158	4154	4207	4279	4359	4445	-999	-999	-999
4294	4261	4173	4139	4227	4282	4157	3951	3941	4102	4191	4190	4174	4183	4249	4322	4389	4442	-999	-999	-999
4300	4279	4235	4262	4339	4316	4148	3953	3969	4157	4251	4236	4206	4200	4237	4333	4436	4477	-999	-999	-999
4279	4283	4303	4338	4362	4281	4089	3962	4064	4256	4307	4275	4262	4256	4252	4307	4423	4516	-999	-999	-999
4229	4273	4332	4359	4317	4181	3997	3999	4191	4335	4371	4367	4346	4331	4335	4334	4382	4507	4598	-999	-999
4202	4297	4322	4296	4208	4061	3956	4015	4189	4356	4469	4496	4448	4409	4432	4422	4415	4514	4649	-999	-999
4165	4315	4319	4224	4089	3998	4033	4069	4105	4260	4418	4500	4510	4495	4505	4503	4518	4602	4638	-999	-999
4085	4241	4302	4198	4039	4037	4189	4237	4165	4151	4244	4424	4556	4582	4579	4577	4605	4696	-999	-999	-999
4117	4217	4258	4146	4062	4178	4328	4402	4374	4258	4228	4424	4626	4676	4667	4660	4683	4716	-999	-999	-999
4258	4304	4237	4079	4106	4290	4391	4481	4529	4445	4362	4468	4653	4735	4739	-999	-999	-999	-999	-999	-999
4325	4369	4273	4103	4138	4332	4433	4518	4592	4583	4539	4549	4652	4750	-999	-999	-999	-999	-999	-999	-999
4319	4402	4376	4229	4141	4293	4473	4551	4619	4685	4685	4653	4707	4786	-999	-999	-999	-999	-999	-999	-999
4273	4391	4449	4352	4172	4209	4433	4561	4629	4707	4703	4682	4742	-999	-999	-999	-999	-999	-999	-999	-999
4260	4332	4411	4444	4315	4218	4360	4514	4585	4627	4623	4647	4698	-999	-999	-999	-999	-999	-999	-999	-999
4343	4331	4372	4502	4450	4289	4369	4513	4557	4607	4666	4716	4734	-999	-999	-999	-999	-999	-999	-999	-999
4450	4430	4435	4511	4470	4319	4373	4511	4585	4725	4848	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
4513	4539	4557	4560	4511	4366	4319	4425	4564	4764	4899	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
4513	4608	4661	4662	4534	4498	4334	4375	4506	4646	4761	4787	-999	-999	-999	-999	-999	-999	-999	-999	-999
4469	4641	4713	4733	4732	4605	4372	4359	4490	4559	4629	4717	4760	-999	-999	-999	-999	-999	-999	-999	-999
4424	4627	4714	4733	4730	4614	4383	4345	4519	4640	4686	4748	4792	-999	-999	-999	-999	-999	-999	-999	-999
4379	4506	4615	4680	4685	4600	4451	4358	4466	4695	4789	4805	4811	4809	-999	-999	-999	-999	-999	-999	-999
4437	4410	4453	4600	4677	4632	4566	4439	4397	4591	4759	4806	4817	4807	-999	-999	-999	-999	-999	-999	-999
4600	4525	4446	4540	4551	4700	4664	4565	4443	4502	4691	4809	4819	4807	4806	-999	-999	-999	-999	-999	-999
4663	4660	4596	4593	4703	4755	4724	4691	4577	4471	4599	4769	4791	4794	4806	-999	-999	-999	-999	-999	-999
4617	4652	4683	4712	4756	4779	4772	4793	4705	4512	4524	4703	4776	4793	4819	-999	-999	-999	-999	-999	-999
4567	4614	4682	4780	4826	4825	4828	4820	4758	4617	4555	4710	4842	4852	4866	-999	-999	-999	-999	-999	-999
4500	4579	4666	4771	4840	4882	4882	4827	4797	4724	4623	4725	4876	4915	4939	-999	-999	-999	-999	-999	-999
4400	4500	4602	4705	4806	4874	4876	4861	4867	4785	4663	4738	4891	4959	4991	-999	-999	-999	-999	-999	-999
4314	4375	4449	4557	4659	4764	4789	4848	4896	4835	4720	4759	4922	5001	-999	-999	-999	-999	-999	-999	-999
4385	4385	4382	4433	4521	4637	4725	4796	4858	4875	4806	4772	4896	5002	-999	-999	-999	-999	-999	-999	-999
4407	4460	4514	4530	4505	4569	4666	4731	4825	4900	4865	4817	4882	4977	-999	-999	-999	-999	-999	-999	-999
4347	4408	4574	4653	4610	4575	4588	4667	4838	4944	4916	4891	4911	4953	4992	-999	-999	-999	-999	-999	-999
4408	4370	4514	4640	4586	4691	4643	4662	4837	4961	4961	4959	4959	4975	5014	-999	-999	-999	-999	-999	-999
4473	4416	4538	4659	4738	4905	4780	4727	4795	4932	5000	5024	5035	5047	5073	-999	-999	-999	-999	-999	-999

a. **Report on the calculation**

b. **Sample grid map**

Figure 16. Sample tabular output report of *MGRIDDER*

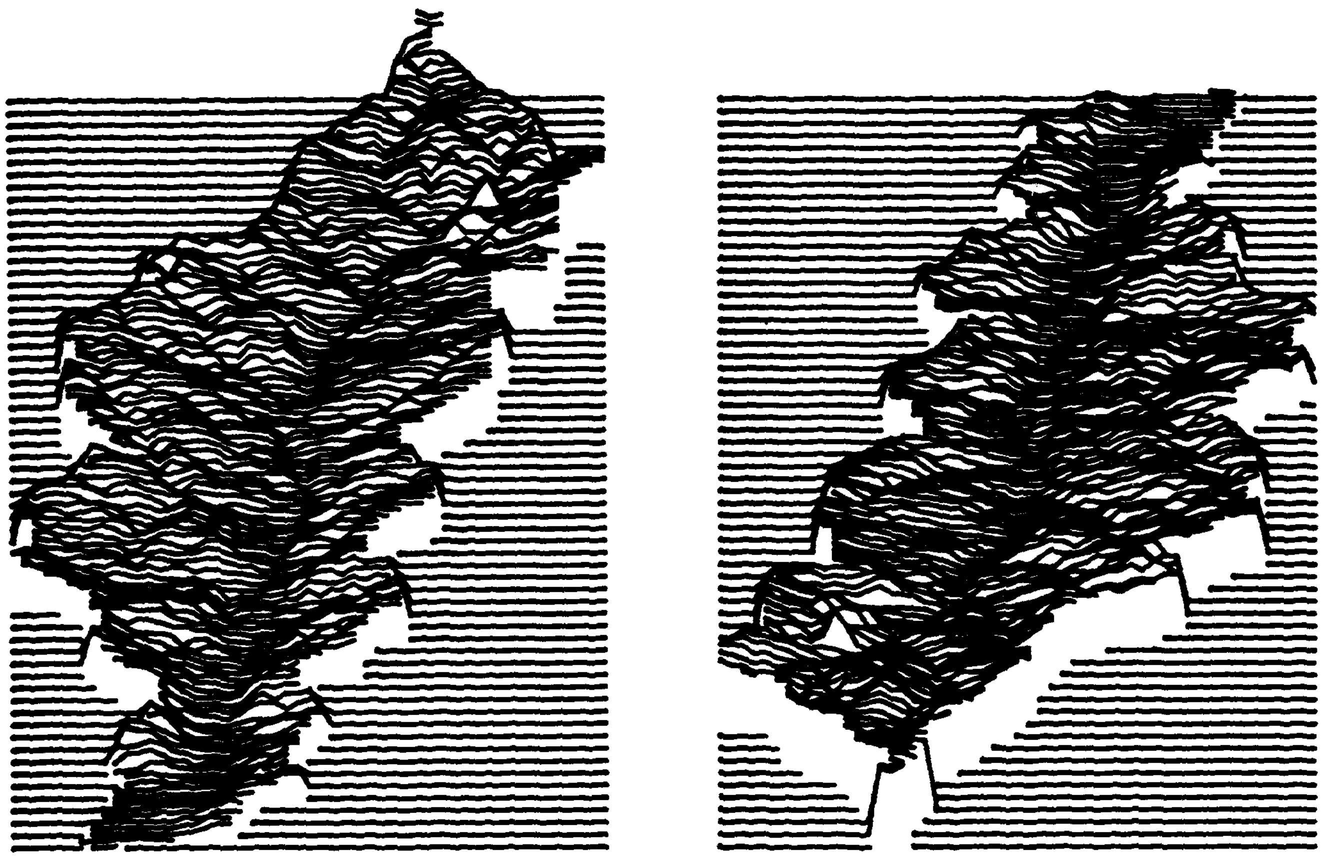
processed without discovery of any suspicious input data or definite errors, except that the program thought the data were sparse in some locales (a total area of 12 grids), which made it difficult to calculate the elevations in those locales. The program was able to resolve the problem by falling back to a secondary procedure for calculating the elevations at those 12 grids. The Figure 16b contains an example of the data grid map provided by MGRIDDER as part of the grid output from the calculation; it contains elevations on a 100-meter grid, with elevation values in units of 0.1 ft. The -999 code values are placed in grids outside the watershed boundary.

98. MGRIDDER outputs the results of the grid calculation to a computer file. The output contains all geographic location, size, and grid spacing information in addition to the grid data shown in Figure 16b. The form and format of the output file is identical to that provided by the program FACGRD used for factor map data.

99. As a further optional quality control step, the gridded data were computer-plotted using a line-plot program, 4VIEW, that provides the three-dimensional appearance graphics shown in Figure 17. These graphics are extremely useful for visually inspecting the topographic data for errors in geographic coordinates and elevation value that have escaped detection up to this point. When held at a distance from the viewer, these graphics are also useful for visualizing the flow pattern on the landscape. Unfortunately, practically no quantitative information can be retrieved from these graphics.

100. The output grid array files for each base map is processed through the program GROW, which adds the data to the spatial master data base. The order in which the map files are submitted to GROW is unimportant since GROW locates the data in the geographic data base according to the information provided in the files. GROW also automatically expands the physical file space of the master data base as part of its automatic data base maintenance function to include space for the new data (ground elevation) when the first set of data is processed.

101. GROW files away the data in the spatial data base only for the geographic region set up with the program EXTENDER. All data



a. View from downstream b. View from upstream

Figure 17. Graphics for final quality control of topographic data

outside the watershed boundary are ignored, so that data for the extra band are trimmed and discarded.

Hydrologic Soil Groups

102. Hydrologic soil group maps were developed for each base map showing the layout of the hydrologic soil groups in the watershed.

103. The soil conservation surveys (SCS and Forest Service 1972, SCS 1964) containing soils data were located and the appropriate pages copied and mosaicked to form soil maps for the Tennessee and Mississippi portions of the watershed, using the map scales at which the data were presented in the soil surveys (i.e., 1:15840 and 1:20,000, respectively). A list of soil types (SCS 1964) encountered in the Tennessee portion of the watershed is shown in Table 4; the soil types for the Mississippi portion of the watershed (SCS and Forest Service 1972) were similar.

104. Soil survey maps are normally constructed in the field by noting the soil survey reconnaissance information on dodged,* large-scale, unrectified aerial photography. The field products are then cut, indexed, provided with coordinates, and compiled into books. The coordinate system used is normally the state planer system, and the coordinate system accuracy on the maps is suspect. The geographic location referencing the soils maps for the watershed was accomplished by computer plotting the digitized elevation data for the upper (Tennessee) and lower (Mississippi) portions of the watershed at scales of 1:15,840 and 1:20,000, respectively. These digitized data could be located on the soils maps by aligning the waterway and its tributaries' digitized thalweg locations with the soils map dodged background. When digitized elevation data and soils maps had been aligned, coordinate location information was transferred to the soils maps. The digitized elevation data computer plots also contained the oversized boundary of the region for which elevation data were gathered (i.e., the watershed boundary

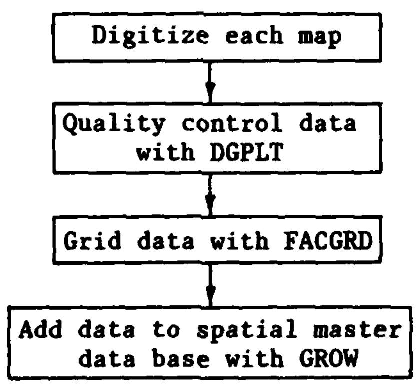
* Optically filtered to wash out boundary edges and most other information while retaining enough photographic information to intimate the type of land cover.

plus an external extra band) and this was transferred to the soils maps.

105. Using the relationship between soil type and hydrologic soil group in Table 5, the hydrologic soils boundary lines were delineated to provide the hydrologic soil groups maps. Figures 18 and 19 show soils and hydrologic soil group maps for the upstream geographic region of the watershed. The hydrologic soils code used in Figure 19 is identified in the tabulation below and matched with its corresponding SCS code.

Hydrologic Soils Code	SCS Code	Runoff Potential
1	A	Low
2	B	Moderate
3	C	Above average
4	D	High

106. The hydrologic soil group data were digitized and processed using the following schedule. The first three steps in the schedule were described in paragraphs 90 to 91 in the section on the watershed boundary. The last step involving the use of GROW to add data to the master data base was described in paragraph 100 in the section on topography.



Land Use

107. Land use data were developed using a combination of previously available land use maps and the interpretation of aerial photography. Land use maps for the eastern regions of Tennessee and northeastern Mississippi that had been prepared by the SCS were located at

Figure 18. Sample of a soils map

Figure 19. Sample of a hydrologic soil group map

the SCS Regional Service Center, Ft. Worth, Texas. These data, in digital form, were computer-plotted to the scale of the base maps. It was found that the spatial resolution of the data was poor and the accuracy inadequate and that the coordinate referencing of the data was considerably displaced and distorted. These data, plotted as accurately as possible to the base map scale, were manually overlaid onto the base maps, and the base maps (i.e., the aerial photograph maps--see Figure 9) were used to correct the available required data by means of photointerpretation.

108. The land use classes used in the mapping are shown in Table 6. These classes consist of a description of both the ground cover and the land use practice. Table 6 is presented in the form normally seen in hydrologic studies, although the classes usually change from one study to another. A sample land use map is not included in this report since it has the same appearance as the soils and hydrologic soils group factor maps (Figures 18 and 19).

109. The land use overlays to the base maps were digitized and processed in a manner identical to the hydrologic soil group overlay data digitizing and processing. (Figure 13 is a sample FACGRD report for part of a land use map.)

Spatial Data Base Transformation

110. When the topographic, hydrologic soil group, and land use data have been placed in the spatial master data base, the data base is completed. The geographic information system approach to construction of this data file provides a convenient means of data file construction, and this approach is essential when the watershed information is spread over parts of several base maps. A Corps study is rarely contained on one base map.

111. While the form and format of the spatial data base are designed to make construction of the data base convenient, they are not readily usable in the calculation phase (see Figure 1) of the work. The program COMBDATA is used to transform the data into the more readily

usable form. COMBDATA also calculates the minimum dimension rectangular site boundary that will enclose the study watershed. COMBDATA provides an output data file with an appearance identical to the form and format of the data files output by program FACGRD and MGRIDDER, except that the three types of information for each grid are compressed into a single number with the following format:

```
XX/XX/XXXXX
|  |    |
|  |    └──────── Ground elevation
|  └───────────── Land use
└──────────────── Hydrologic soil group
```

112. This output file is used by the program STRTFLOW that prepares the flow allocation network as described in Part IV of this report.

Channel Location

113. The locations of the stream channel are required in the flow calculations to provide information as to where the storm runoff changes from overland to channel flow. This is provided by locating all grids through which stream channels flow using the program CHANLOC. This operation is the last data preparation and processing step shown in the principal schedule of work shown in Figure 6. The program CHANLOC is used to process the digitized topographic data for each base map (these are the same data that were input to program MGRIDDER). After using CHANLOC on all digitized topographic data, the output files from CHANLOC must be merged to provide gridded channel location data for the total watershed.

114. The functions provided by CHANLOC are as follows. The program ignores all area-of-interest and ground elevation data in the digitized topographic data file. Only the channel location digitized data are processed. CHANLOC transforms the channel location data from the digitized coordinate system to the grid coordinate system. The program requires the user to specify the desired grid spacing and the diagonal

corner coordinates of the minimum-sized rectangular box placed about the site by the program COMBDATA. CHANLOC uses the coordinate location information on the digitized data file and the input coordinates of the total watershed site boundary box to calculate the channel-located grid coordinates. Finally, CHANLOC rectifies the digitized channel location data, using the same algorithm as FACGRD, during the transformation from digitizer to grid coordinates.

115. Figure 20 shows a computer plot of the total channel network for the study watershed produced by program DGPLT.

Rainfall Intensity Function

116. Since the object of this study was the development of a flow simulation procedure that would be used either for actually recorded or synthetic storms, it was unnecessary to perform a stage/discharge/rainfall/frequency-of-occurrence correlation. Data for such calculations are readily available and are commonly used in flood studies; sources include National Weather Service records for meteorological stations and publications (Randolph and Gamble 1976, Colson and Hudson 1976) on storm magnitudes and frequencies prepared by the USGS in conjunction with State agencies. Dean and Snyder (1977) provide a concise overview of mathematical procedures used for preparing rainfall data from multiple gage data. A synthetic rainfall record, shown in Figure 21, was used in all flow calculations in this study; this 2-in. cumulative rainfall represents a flood event storm with a repeat period of approximately 10 years for the study watershed.

117. The tabular data in Figure 21 is a listing of the rainfall data base. The first column contains the file record line numbers; the first data line contains the time interval (0.5 hours) and the cumulative storm rainfall (2.0 in.). The remaining records contain the rainfall intensity, in arbitrary units, at successive values of the time interval to be used in the flow calculation.

118. The rainfall time distribution was plotted in arbitrary units on the graph shown in Figure 21; synthetic rainfall curves are

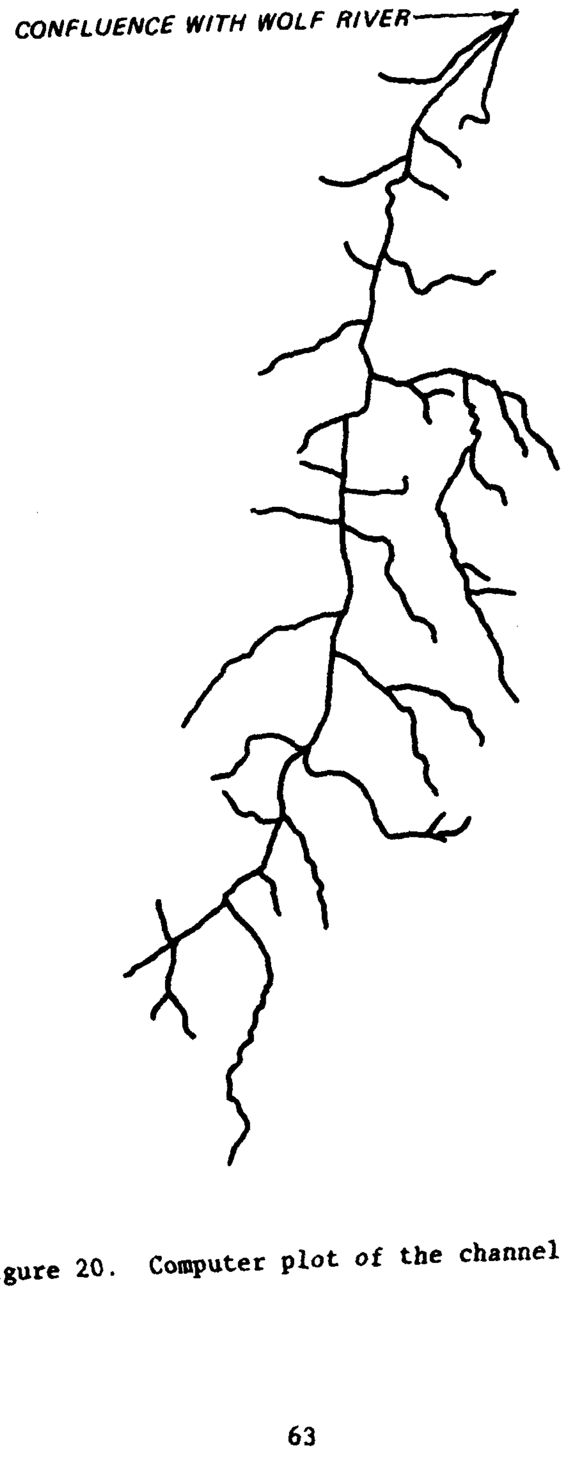


Figure 20. Computer plot of the channel network

```
10000  .05.2.0   (2-INCH RAINFALL, 0.05-HR INTERVALS)
10001  0.00  0.0
10002  0.05  0.4
10003  0.10  1.0
10004  0.15  2.0
10005  0.20  4.0
10006  0.25 14.0
10007  0.30 26.0
10008  0.35 42.0
10009  0.40 56.0
10010  0.45 67.0
10011  0.50 80.0
10012  0.55 80.0
10013  0.60 80.0
10014  0.65 80.0
10015  0.70 80.0
10016  0.75 80.0
10017  0.80 80.0
10018  0.85 80.0
10019  0.90 80.0
10020  0.95 80.0
10021  1.00 80.0
10022  1.05 78.0
10023  1.10 60.0
10024  1.15 36.0
10025  1.20 20.0
10026  1.25 13.0
10027  1.30 10.0
10028  1.35  7.5
10029  1.40  6.0
10030  1.45  4.0
10031  1.50  3.0
10032  1.55  2.3
10033  1.60  2.0
10034  1.65  1.0
10035  1.70  0.8
10036  1.75  0.5
10037  1.80  0.4
10038  1.85  0.3
10039  1.90  0.2
10040  1.95  0.1
10041  2.00  0.0
```

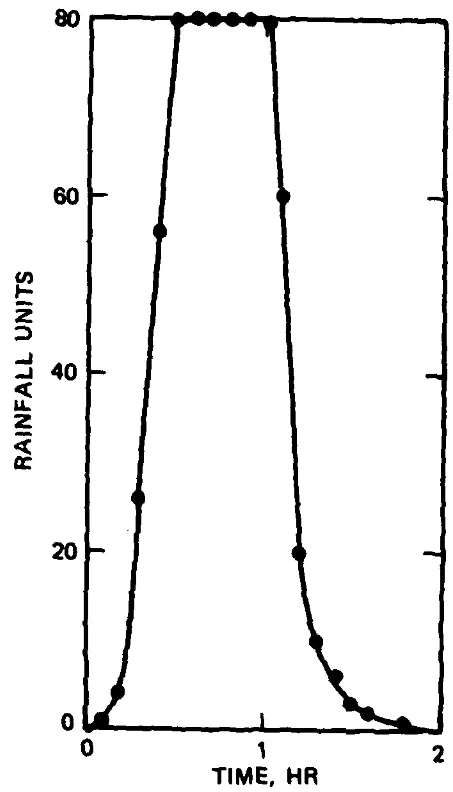


Figure 21. Rainfall time distribution used in this study

frequently prepared in this manner prior to normalizing the rainfall amplitude to the quantity necessary for the flood frequency storm event under study. As described in Part IV of this report, this normalization step was made part of the flow allocation calculation for convenience of the user.

PART IV: CALCULATIONS

119. The final result of the data preparation and processing is a geographic information system data base which has been processed through program COMBDATA. This data base contains all information required for the setup for surface flow calculations. This data base and the subsequent calculation steps involving these data are shown in Figure 22.

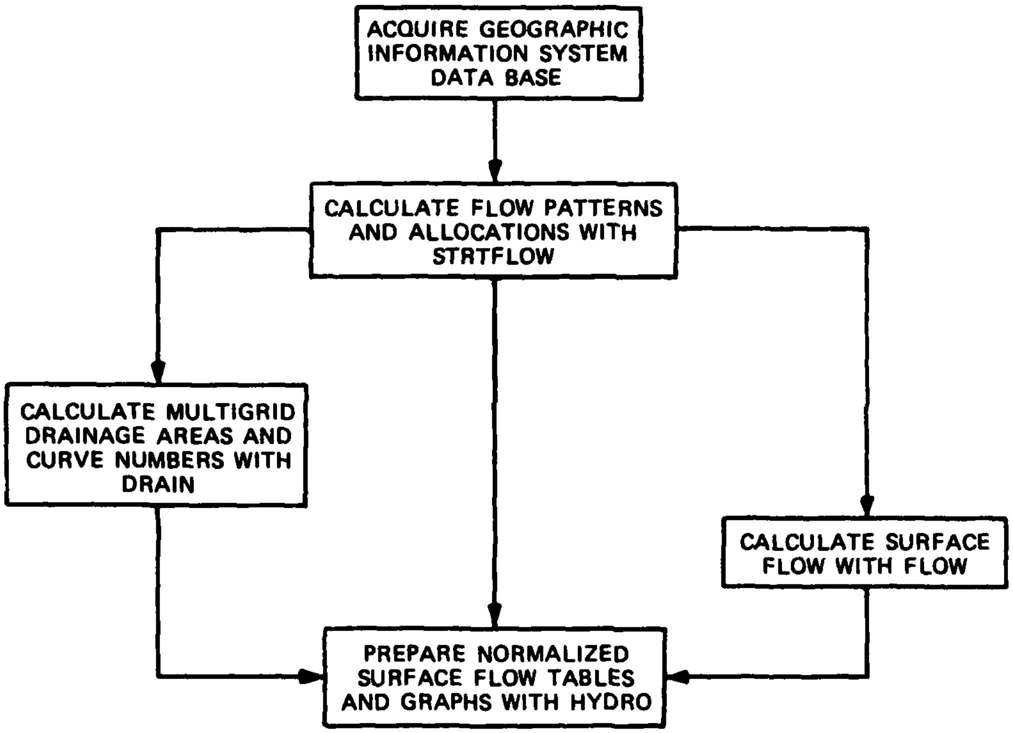


Figure 22. The calculation effort

120. The desired calculation result is the surface runoff time history (a) for rainfall, (b) for grid-to-grid flow, and (c) for the total surface flow for every grid in the watershed. It is necessary to separate the two water movement components since they play different roles in erosion problems. The total surface flow is a sum of the two components.

121. The separation of calculation work into rational stages shown in Figure 22 was actually designed to achieve flexibility in the use of the system and to minimize redundant computer calculations. For example, a study of the effects of different storms for the same watershed requires the one-time use of all computer programs up to but not including FLOW and HYDRO, and the use of FLOW and HYDRO for each of the storm conditions. Various important flexibility options are described in the appropriate sections of this report part.

122. The calculational algorithms used in programs referenced in Figure 22 are described in detail in this part of the report. The interested reader can obtain listings of the computer programs from the author to study how the algorithms were implemented in the computer software. The implementation of the algorithms in a simple, straightforward, affordable manner involved a significant effort in this study; as a result, the computer code implementation is often easier to understand than the mathematical expressions provided in this report that describe the implementation.

123. Several crucial assumptions and approximations were incorporated into the system. These assumptions and approximations, described at the appropriate places in this part of the report, were necessary to make the calculation tractable and terminable in a reasonable time and fashion. For example, since the system is used to calculate surface flow "hydrographs" with asymptotically decreasing flow function tails, a decision was made to break off the iterative grid-to-grid flow calculation when the flows reached values that had a negligible effect on the cumulative flow volume through a grid. The reason for connecting the cutoff decision with this parameter is given in the description of the computer program HYDRO. The assumptions and approximations implemented in the system development enabled the calculational costs to be reduced several orders of magnitude from the initial to the final form of the system. The present form of the system permits a flow calculation (using program FLOW) on 2999 grids of 100 m × 100 with a time increment of 0.05 hour for flows out to 2.7 hours for an approximate cost of $17 on the Honeywell version DPS computer.

124. All assumptions and approximations incorporated in the system calculational procedures are consistent with the accuracy of normally available data and the rainfall runoff and lag relationships used in the calculations.

Flow Patterns and Allocations

125. The program STRTFLOW prepares the ground elevation data for the flow calculation by ensuring continuous flow patterns to the channels, assigns runoff curve numbers to each grid, and allocates the flow from each grid to neighboring grids to set up the grid-to-grid flow pattern.

Pit Removal

126. It is assumed that all flow channels are identified in the channel location data base. This data base is input to STRTFLOW, which codes every grid named in the channel data base as a "channel grid." This designation remains with each of these grids throughout all subsequent calculations. The significance of the channel grids is that they form a mathematical sink for all surface flows. That is, any surface flows that enter a channel grid are assumed to terminate in a channel after flowing across the grid, and leave the flow accounting system. It is further assumed that all surface flows sooner or later enter a channel grid, i.e., the only way for any flow to leave the accounting system is to reach a channel grid.

127. Provided that the watershed boundary and channels have been properly delineated and the ground elevation information provides a reasonably accurate picture of the topographic trend surface, the only reasons flow lines cannot terminate in a channel grid are (a) ponding conditions on the landscape or (b) elevation depression artifacts generated in processing the data. Topographic maps at 1:62,500 and larger scale do provide reasonably accurate trend surface information. In addition, the Corps normally corrects the contour maps in planning studies using data from valley cross-section surveys which are required for backwater, stage/storage, and stage/area flooded design and for economic evaluations

in the floodplains. The floodplains are the low-relief regions of the watershed, and this additional information aids in removing any ambiguities in the locale of the channels where the trend surface information provided by topographic maps is most sparse and where there is greatest potential for disagreement between the map data and ground conditions.

128. This developed system assumes that runoff from a grid is characterized by the curve number relations described in paragraphs 43-61. That is, it is assumed that ponding does not occur or is negligible. It is possible to incorporate ponding effects into the system by designating grid points for ponds just as grid points are designated for channels in the present system. The present system runoff procedure could be modified to provide storage and controlled drainoff from the ponded regions.

129. Depression artifacts are generated in processing the data since a regular grid pattern layout can step over small linear drainage features and provide what appear to be slight depressions or "pits." A "pit" is defined as a region, at least 1 grid in size, that is the terminus of a flow pattern(s) and is not and does not contain a channel. It is also possible for pits to be generated by the algorithm used in transforming the ground elevation data into the grid coordinate system. These minor problems are insignificant, however, compared with the advantage of using an automatically generated regular grid system rather than an irregular, manually delineated grid to model the terrain: the automated approach is cheaper, uses fewer man-hours, and generates a larger number of grids; the manual method suffers from a subjectively irregular grid layout.

130. STRTFLOW automatically searches for pits in the data base and corrects the elevation data by adding a small value to the elevation of the pit grid(s). The pit search is performed by examining the entire data base while performing the following calculation at each grid location.

$$\Delta Z = Z_{I,J} - Z_{II,\ JJ} \left| \begin{array}{ll} II = I - 1,\ I + 1 & \\ JJ = J - 1,\ J + 1 & Z_{II,JJ} \neq -999 \\ II,\ JJ \neq I,\ J & Z_{I,J} \neq \text{channel} \end{array} \right. \qquad (7)$$

where I,J are the coordinates of the grid being tested for a pit and II,JJ are the eight nearest-neighboring grids. The calculation is voided for the selftest (i.e., II = I, JJ = J), where a nearest-neighboring grid lies outside the watershed (i.e., $Z_{II,JJ} = -999$), and where the grid being tested contains a channel.

131. If $\Delta Z < 0$ for all II, JJ , then the grid I, J is a pit. A record is kept of the largest ΔZ value, that is, the smallest ΔZ negative value. The value of the pit grid is corrected as follows.

$$Z_{I,J} = Z_{I,J} + \left| \Delta Z_{max} \right| + 10.0 \qquad (8)$$

Since the elevation units are in 0.1-ft increments, the elevation value of the I, J grid is reset to 1 ft above the elevation of the nearest neighboring grid with the lowest elevation.

132. The operation in which the entire data base is searched one time, grid-by-grid, for pits is called a "pass." A series of passes is made on the data base until no pits are located during a pass, at which time the pit-removal algorithm is terminated. Passes are made from top to bottom and bottom to top, alternatively, on the topography grid model to enhance the probability of pit location with fewest passes; the maximum number of passes that will be allowed in a calculation is preset into the program to ensure against a runaway condition. For example, if a portion of the channel network is not identified and located in the data base, STRTFLOW will identify most of the unidentified channel grids as pits and attempt to iteratively correct what it identifies as a large-scale pit problem. If the number of preset passes is exceeded, the program terminates after providing a copy of the full data base on magnetic tape containing all corrections performed thus far. This enables the user to restart the calculation where it was terminated, or to correct

the channel or ground surface elevation data, if required, and restart the entire calculation.

133. Note, as implied in Part III, that "top" and "bottom" refer to the coordinate system and not to the watershed alignment. When the UTM or a state planar coordinate system is used, top and bottom are approximately oriented north and south, respectively. The fact that the study watershed is oriented north-south (Figure 7) is accidental and has no bearing on any calculations performed by the system.

134. The output report of STRTFLOW provides a list of all pits and their corrected values for each pass as shown in the example in Figure 23. The example shown in Figure 23, for a grid with 100-m spacing on the study watershed, is typical. The number of pits located in this example was less than 0.13 percent of the total number of grids covering the watershed, and the maximum elevation correction changed the ground slope at a pit grid less than 1 percent. The pit removal procedure, therefore, performs a correction necessary before a flow calculation is mathematically possible, and the size of the correction on any grid is expected to have a negligible effect on the overland flow results.

Curve Numbers

135. The data base input to STRTFLOW contains land use and hydrologic soil group data for every grid in the watershed. The relationship between these parameters and curve numbers is provided in a table, also input to STRTFLOW. The curve number relations for average antecedent moisture conditions used in this study (see Table 7) are approximately the same as those used in Corps studies for the local region of the study watershed. Low or high antecedent moisture conditions curve number sets or curve numbers corrected for study conditions on the landscape could be used in place of the listed values. It is also possible to develop and use a set of land use classes and curve number references completely different than those shown in Table 7.

Flow Allocation

136. STRTFLOW calculates, for every grid within the watershed, the allocation of flow from that grid to other neighboring grid(s) for a

****PIT REMOVAL REPORT****

PASS	PIT GRID COORDINATES X	Y	NEW Z
1			
	47	2	3351
	39	4	3408
	33	5	3711
	44	10	3378
	44	13	3407
	44	14	3417
	34	19	3472
	34	21	3501
	35	23	3611
	32	26	3557
	34	38	3511
	34	40	3611
	53	43	4508
	35	49	4294
	34	57	4111
	34	58	4120
	41	64	4369
	40	85	4834
	39	85	4845
	40	85	4856
	39	85	4867
	40	85	4878
	39	85	4889
	40	85	4891
	39	86	4895
	41	86	4902
	6	87	4927
	39	87	4906
	41	89	4823
	31	94	4986
2			
	39	85	4902
	40	85	4905
	40	84	4913
	34	37	3522
	38	3	3410
	39	2	3413
3			
	34	38	3533
	39	86	4913
	41	86	4916
	39	87	4917
4			
	39	85	4916
	40	85	4917
	40	84	4927
	34	37	3544
5			
	34	38	3552
	40	86	4924
	41	86	4928

****PIT REMOVAL REPORT****

PASS	PIT GRID COORDINATES X	Y	NEW Z
	39	86	4927
	39	87	4935
6			
	39	85	4928
	40	85	4935
	40	84	4939
	33	37	3555
	34	37	3563
7			
	34	38	3566
	40	86	4938
	41	86	4946
	39	86	4939
	39	87	4949
8			
	39	85	4946
	40	85	4949
	40	84	4957
	33	37	3574
	34	37	3577
9			
	34	38	3585
	40	86	4949
10			
	33	37	3587
11			
	33	38	3588
12			
	34	37	3589
	34	36	3595
	33	36	3598
13			
	34	38	3598
14			
	33	37	3599
15			
	33	38	3600
16			
	34	37	3606
	34	36	3609
	33	36	3610
17			
	34	38	3610
	34	39	3611
18			
	33	37	3611
19			
	33	38	3617
	33	39	3621
20			
	34	37	3620
	34	36	3621
	33	36	3622
21			
	34	38	3622
	34	39	3622
22			
	33	37	3628
23			

Figure 23. Pit removal report example from STRTFLOW

unit time interval Δt . The basis of this flow allocation is the flow lag and the local topographic slope. The lag equation used in this study is as follows:

$$L = \frac{\ell^{0.8}[(1000/CN) - 9]^{0.7}}{1900\sqrt{S}} \tag{9}$$

where

L is the flow lag in hours

ℓ is the hydrologic length of flow

CN is the curve number

S is the percent slope

This lag equation is applied to every grid to calculate the amount of flow in temporary storage on the grid at time t that will flow from the grid by time $t + t$. Specifically, the desired value is $L_{I,J}/\Delta t$, the <u>fraction</u> of the flow in temporary storage on grid I at time t that will be removed to the neighboring J grids during Δt . As seen from the equation, this fraction is a function of the grid curve number and the slope and hydrologic length of flow.

137. An inherent assumption in this approach is that the rainfall does not vary rapidly in intensity over a time interval less than Δt, since the approach assumes a smoothly varying flow intensity. The flow consists of both the noninfiltrated rainfall for the grid (i.e. direct rainfall flow) and the flow from other grids (i.e. grid-to-grid flow) across the grid. The grid-to-grid flow intensity history is buffered from the rainfall intensity history, and the grid-to-grid flow function shape through time is influenced by the flow network. It is also generally true that the grid-to-grid flow component is larger and dies out much more slowly than the rainfall flow component <u>except</u> for grids that have little or no uphill drainage area.* The net effect is that rapid rainfall intensity changes are rapidly smoothed and do not strongly influence the system results.

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* The section on drainage area expands on this topic.

138. The mean travel distance across a grid was used for the grid hydraulic length

$$\ell = \frac{2D}{\sqrt{\pi}} \tag{10}$$

where D is the grid spacing in feet.

139. An approximation of the average slope at each grid was calculated for S in Equation 9. The following procedure was used for all grids that did not contain channels:

$$S_{I,J} = \frac{\sum_{II=1}^{3} \sum_{JJ=1}^{3} \left| Z_{I,J} - Z_{II,JJ} \right| / R_{II,JJ}}{\sum_{II=1}^{3} \sum_{JJ=1}^{3} 1/R_{II,JJ}} \qquad \begin{array}{l} \left(Z_{I,J} - Z_{II,JJ}\right) > 0 \\ II,JJ \neq I,J \end{array} \tag{11}$$

where

$R_{II,JJ}$ is the grid-to-grid distance, so that

$R_{II,JJ} = D$ for horizontal and vertical grids to the I,J position

$R_{II,JJ} = \sqrt{2}\,D$ for the diagonal grids to the I,J position

D is the grid spacing in meters

The calculation uses all downhill slopes to neighboring grids from the I,J position to calculate the average slope for grid I,J. For grids containing channels, the flow proceeds across the grid into the channel, so there are no downhill neighboring grids. It was assumed that a channel grid's downhill slope to the channel is approximately the same as the downhill slope to that grid from neighboring grids. Equation 11 was modified for channel grids as follows.

$$S_{I,J} = \frac{\sum_{II=1}^{3} \sum_{JJ=1}^{3} \left| Z_{II,JJ} - Z_{I,J} \right| / R_{II,JJ}}{\sum_{II=1}^{3} \sum_{JJ=1}^{3} 1/R_{II,JJ}} \Bigg| \begin{matrix} \left(Z_{II,JJ} - Z_{I,J}\right) > 0 \\ II,JJ \neq I,J \end{matrix} \quad (12)$$

where $R_{II,JJ}$ has the same meaning as it does for Equation 11.

140. At the completion of the calculation, the value of $L_{I,J}/\Delta t$ is the fraction of the flow temporarily stored on grid I,J that will flow from the grid to its neighbors in the next time increment Δt .

141. STRTFLOW allocates the flow to the neighboring grids of a nonchannel grid using the nearest-neighbor slope values in the following method in which all uphill relationships are ignored:

$$s_{I,J}^{II,JJ} = (Z_{II,JJ} - Z_{I,J})/R_{II,JJ} \Big| \; s > 0 \quad (13)$$

where $s_{I,J}^{II,JJ}$ is the slope from grid I,J to grid II,JJ .

The flow $L_{I,J}/\Delta T$ is then allocated to the neighboring grids by using the normalized slope values of Equation 13 as follows:

$$\frac{L_{I,J}^{II,JJ}}{\Delta t} = \frac{L_{I,J}}{\Delta t} \frac{s_{I,J}^{II,JJ}}{\sum_{II=1}^{3} \sum_{JJ=1}^{3} s_{I,J}^{II,JJ}} \Bigg| \begin{matrix} s > 0 \\ II,JJ \neq I,J \end{matrix} \quad (14)$$

where $L_{I,J}^{II,JJ}/\Delta t$ is that fraction of the flow temporarily stored on grid I,J at time t that is allocated to flow to grid II,JJ in the next time interval Δt .

Output File Structure

142. The data file input to STRTFLOW has the same general format as the grid array data files output from programs FACGRD and MGRIDDER. Examples of the gridded data portion of this type of file were shown in Figures 13c and 16b. The data generated by STRTFLOW include a list of nearest neighbors and the flow allocation schedule for these neighbors

for each grid. Because of the dramatic increase in the volume of information that must be retained for each grid to support the subsequent flow calculation, the data file format is changed. In the STRTFLOW output format, only those grids within the watershed boundary are retained in the data file. Each grid within the watershed is assigned a unique identification number assigned sequentially from top to bottom, left to right of the data array input to STRTFLOW; the assignment has no correlation with the watershed alignment or water flow pattern. The identification assignment number of each grid is also used as the file location (in a randomly written file) of the data for that grid. The substitution of sequential identification numbers that also double as random file pointers for each grid in place of the grids' X,Y coordinates is crucial to the calculation. It is not possible, even with data compression techniques, to maintain all data required for the flow calculation of a small watershed in the memory space available in a large mainframe computer. Alternatively, the use of mass storage devices and data input/output swapping techniques permits the storage of the required data but involves an operational cost that makes calculations unacceptably expensive even for small watersheds. The use of the developed sequential identification numbers as random file pointers, however, is one key to decreasing the calculation cost and time several orders of magnitude so that the flow calculation becomes inexpensive.

143. The data stored for each watershed grid is shown in the tabulation below.

Record Word	Contents
1	X UTM grid coordinate
2	Y UTM grid coordinate
3	Channel/nonchannel identification 0 = no channel passes through the grid 1 = channel passes through the grid
4-11	Grid (record) identification numbers of the nearest neighbors to this grid
12-19	Percent of flow apportioned to each of the neighboring grids listed in words 4-11
20	Grid curve number

144. The X,Y coordinates of each grid are maintained so that it is possible to transform the sequential identification (record) number back to geographic coordinate space. The X,Y coordinates are conveniently arranged from large to small Y value, and from small to large X value for any given Y value. That is, the data are arranged from top to bottom, left to right, on a map of the watershed.

145. The channel/nonchannel and curve number data are retained for use in the flow and infiltration portion of the flow calculation, respectively.

146. There are, potentially, eight nearest neighbors for each nonchannel grid. The data stored in words 4-11 are the identification (record location) numbers for the grid's nearest neighbors to which there is flow. The eight-nearest-neighbor sequencing pattern to the central grid is shown below. The identification number for the number 1 nearest

1	2	3
4	X	5
6	7	8

neighbor goes into word 4, etc., for the number 2 nearest neighbor into word 5, etc., for the central grid's data record. If no portion of the flow is allocated to a given nearest neighbor or if there is no nearest neighbor in a given position, its word value is set to zero.

147. The flow allocations stored in words 12-19 for each grid are the flow allocation data $L_{I,J}^{II,JJ}$ *1000/t for each nearest-neighboring grid. The data are multiplied by 1000 to provide the data in integer format with sufficient accuracy for use in the flow calculation.

148. If a grid is a channel grid, all flow is assumed to go into the channel and the total flow allocation from that grid is placed in

word 12. All other flow allocation storage locations as well as the address locations of the nearest neighbors are set to zero.

Constant Flow Allocation

149. The flow allocation network is calculated by STRTFLOW for a predetermined grid interval and time interval and for infiltration and lag characteristics that retain constant values over time. The physical relationships used as the bases for this study and for all Corps hydrologic calculations, whether based on curve numbers or something more rudimentary, also assume constant infiltration and lag characteristics. Note that these parameters are adjusted in all Corps studies to meet calibration criteria for presumably known individual storm conditions, but the parameters do remain constant over time. The two reasons why this approach is so widespread is that (a) the vast majority of the work performed in the technical area is with statistically derived storm conditions and (b) the normally available data for a given watershed cannot provide infiltration, etc., data as a function of time.

150. It is possible to modify the developed system to accommodate time-varying infiltration and lag conditions. This can be done most conveniently in the flow calculation without any modification to STRTFLOW. (The approach is discussed in the section Time-Varying Flow Allocation, paragraph 256.) Time-varying flow allocation calculations are of interest mainly in studies designed to develop better infiltration and flow relationships on calibrated watersheds.

Single-Nearest-Neighbor Flow Option

151. In addition to generating flow allocations to all eight nearest neighbors, STRTFLOW can also set up the flow allocation using only a single-nearest-neighbor flow pattern for each grid. If this option is selected, the allocation algorithm locates the maximum slope direction among the eight nearest-neighbor directions and selects that nearest neighbor in the maximum slope direction as the grid to which the total allocated flow in Δt will move.

152. The output file produced by STRTFLOW for this option is identical to the flow produced when the eight-nearest-neighbor flow option is selected except for a modification in the appearance of the output

file. Specifically, the address location for the nearest neighbors (words 4-11) are all set to zero except for the nearest neighbor selected to receive the total flow; the flow allocation locations (words 12-19) are all set to zero except that location corresponding to the single nearest neighbor selected. The flow allocation value is set to $L_{I,J}$ *1000/Δt . There is no modification of the records produced for channel grids since the assumption that total flow from these grids moves into a single location, the channel, remains unchanged.

153. The original reason for designing a single-nearest-neighbor flow pattern option was the assumption that surface flow function time histories for the single- and eight-nearest-neighbor conditions would be practically indistinguishable. The desire for this assumption to be proven true was fostered by the significant cost savings of a single- over an eight-nearest-neighbor flow pattern calculation in the early stages of the systems' development (the cost differs by a factor of 2-5). The design of the final system with a dramatic decrease in operation cost, so that there is little cost difference between the options, softens the disappointment in finding that the single-nearest-neighbor may yield the same results as the eight-nearest-neighbor flow calculation, only under a certain restricted condition. This condition, basically a simple statistical one, is that the flow patterns on the landscape are complex enough and are routed through enough grids so that the cumulative grid flows through any one typical grid average out to the same value whether single- or eight-nearest-neighbor algorithms were used. Another way to state this condition is that the uphill drainage area for a typical grid would be statistically large enough, whether single- or eight-nearest neighbor flow patterns are used, that the drainage areas calculated using the two procedures would be approximately the same.

154. Calculations run on the study watershed and on two other watersheds during the early development stages of the system indicated that the channel network is such that few locations in the watershed are far enough from a channel to permit many grids to have a large drainage area. As a demonstration, Table 8 shows the study watershed drainage

area frequency distributions for the single- and eight-nearest-neighbor flow pattern algorithms, for bases with both 100- and 200-m-grid spacing for the study watershed. The peaking of the distributions at the minimum grid area value and the exponentially decreasing amplitude of the distributions clearly show the problem. The 200-m grid data start at the 4-ha level since the smallest unit of measurement, 200 m, is 4 ha. The distribution spikes in the single-nearest-neighbor results for the 200-m grid are due to the fact that single-nearest neighbor flow requires the drainage areas to be integral multiples of the single grid drainage area.

155. Since the grids' drainage areas for the single-nearest-neighbor flow pattern are measured in the grid system, it is possible to improve the statistics, without changing the drainage area, by decreasing the study grid size. An inspection of Table 8 shows the significant effect achieved when a 100-m rather than 200-m grid is used for the single-nearest-neighbor flow. Table 8 reflects the effect of a fourfold increase in the number of grids in the same area, and the changes in flow patterns associated with increased spatial resolution in the mathematical model of the ground surface. The requirement to use a smaller grid spacing with an associated multifold increase in data volume in order to produce the proper conditions for a single-nearest-neighbor flow pattern approach increases the cost and complexity of the system.

156. The single-nearest-neighbor flow pattern calculation appears to be an unacceptable procedure for normal use, but is a useful tool for investigating whether the time increment used for the flow calculation is excessive. This topic is explored in detail in the next report section, Time Increment Limitations. The single-nearest-neighbor calculation is potentially useful in watershed studies where it is necessary to calculate flow time histories with a high spatial resolution so that the grid spacing produces a drainage area frequency with more amplitude toward the larger drainage area end of the distribution.

Time Increment Limitations

157. A major assumption in this development effort was that a

significant portion of the temporary storage flow from a grid does not pass completely across nearest neighboring grids into (or across) second nearest neighboring grids in the time increment Δt used for the flow calculation. Requiring the conditions of this assumption permits calculations for any given time increment on a grid independent of post or preceding time increment calculations for that grid. If the assumption is violated, the calcuational procedure must be followed over the necessary number of successive time increments; this increases dramatically the computer memory size requirements for this calculation over what is required when the assumption is met. For example, if the flow passes from one grid into its second-nearest neighbors, the memory requirements double; into third-nearest neighbors and the requirements triple; etc. Other even more serious problems that arise are noted in later sections of this text.

158. An alternate to and close approximation of this assumption that can readily be checked is to require time increments such that water in temporary storage on a grid at time t does not totally flow off the grid by time $t + \Delta t$. Minor violations of this requirement do not affect the integrated flow volume time history function from a grid, but do change the flow function shape and particularly the time location of the maximum flow amplitude. A normalization stratagem, described in the sections of the report on programs DRAIN and HYDRO, ensures against incorrectly integrated flow volume errors under practically any violation conditions, but there is no way to avoid maximum amplitude and peak time shift errors if Δt is too large. The shift in the maximum flow amplitude is always toward longer times since the flow calculation results are reported at integral multiples of Δt; that is, if Δt is too large, the flow results are reported later than the time of occurrence that would be reported with a smaller Δt. Although it is unclear when the report results (i.e., flow as a function of time) are significantly distorted for a grid, it is obvious that a Δt that would allow the flow to move to the second-nearest neighbor produces a flow time history in which the function, shape, and peak locations are far removed from true locations. Examples of this effect are shown at the

end of this part in the section on flow time history results.

159. During the STRTFLOW flow allocation calculation, the fraction of the flow from a grid $L_{I,J}/Wt$ is tested to ensure that it does not exceed 1.0. If the value does exceed 1.0, it is reset to a value of 1.0 to conserve mass in the flow calculation. STRTFLOW provides a listing of the output file contents for visual inspection. Figure 24 is an example of the first section of such a report. The values for words 12-19, identified as the "% Apportionment of Flow, Using Slope and Lag Factor" section of data in the tabular output, can be scanned. If the sum of all flow allocations equals 1000 (since the recorded values are $L_{I,J}^{II,JJ}$ *1000/Wt) for a grid, the time increment is too large for that grid's flow.

160. Since the STRTFLOW calculation with the single- rather than eight-nearest-neighbor flow option provides the total flow allocation in a single number, the location of 100 percent flow conditions are obvious in the STRTFLOW tabular output directly as shown in Figure 25 (saturation condition flows are underlined).

Storm Input

161. Most Corps planning studies involve calculations for multiple rainfall storm events with hyetographs statistically constructed from historical storm frequency and duration data. STRTFLOW prepares an output data file for the selected time interval flow calculation that can be used with any number of storm events--statistical, fabricated, or real--without the need for reprocessing any data.

Tabular Output

162. STRTFLOW provides several sets of information in the form of tabular output, some of which has already been presented in Figures 24 and 25 used in prior sections in this report. This section summarizes the major tabular output data and provides a further description of their contents and uses.

a. Curve Number Table. The relationship between curve number, and land use and hydrologic soil group is displayed (Figure 26) to provide a permanent copy of the data used in the calculation.

****REPORT-MASTER FILE PRINTOUT****
TOTAL NUMBER OF GRIDS ON FILE- 2998
FACTOR TO CONVERT ELEVATION DATA TO METER UNITS--1.000
X,Y DIMENSIONS OF ARRAY IN GRIDS- 53 124
GRID SPACING IN METERS-100.00
TIME INTERVAL FOR FLOW CALCULATION - 0.1000

REC NO	GRID LOC X	GRID LOC Y	CHAN / GRID	RECORD ADDRESS OF NEAREST NEIGHBORS 1	2	3	4	5	6	7	8	XX10 APPORT OF FLOW, USING SLOPE AND LAG FACTOR 1	2	3	4	5	6	7	8	CURVE NO
2	44	1	0	0	0	0	0	3	0	0	11	0	0	0	0	205	0	0	122	71
3	45	1	0	0	0	0	0	4	0	0	12	0	0	0	0	194	0	0	141	71
4	46	1	0	0	0	0	0	0	0	12	0	0	0	0	0	0	8	178	0	81
5	39	2	0	0	0	0	0	6	18	19	20	0	0	0	0	50	19	230	30	81
6	40	2	0	0	0	0	0	7	19	0	21	0	0	0	0	99	97	0	77	81
7	41	2	0	0	0	0	0	8	0	21	22	0	0	0	0	274	0	5	163	81
8	42	2	0	0	0	0	0	9	0	0	23	0	0	0	0	243	0	0	99	81
9	43	2	0	0	0	2	0	10	0	0	24	0	0	107	0	155	8	0	107	81
10	44	2	0	0	2	3	0	11	0	24	25	0	3	98	0	165	0	3	129	78
11	45	2	0	0	0	4	0	12	0	25	26	0	0	75	0	155	0	13	75	71
12	46	2	1	0	0	0	0	0	0	0	0	371	0	0	0	0	0	0	0	81
13	47	2	0	4	0	0	12	0	26	0	0	197	0	0	435	0	197	0	0	99
14	34	3	0	0	0	0	0	15	0	0	28	0	0	0	0	635	0	0	349	78
15	35	3	0	0	0	0	0	16	0	0	29	0	0	0	0	705	0	0	210	78
16	36	3	0	0	0	0	0	17	0	0	30	0	0	0	0	671	0	0	161	78
17	37	3	0	0	0	0	0	18	0	0	31	0	0	0	0	240	0	0	78	79
18	38	3	0	0	0	0	0	19	0	0	32	0	0	0	0	283	0	0	21	79
19	39	3	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	140	72
20	40	3	0	0	0	7	19	21	32	33	34	0	0	18	51	40	2	87	60	72
21	41	3	0	0	0	8	0	22	33	34	35	0	0	73	0	122	11	26	58	71
22	42	3	0	0	0	9	0	23	0	0	36	0	0	85	0	99	0	0	47	71
23	43	3	0	0	9	10	0	24	0	0	37	0	8	67	0	126	0	0	102	71
24	44	3	0	0	0	11	0	25	0	37	38	0	0	67	0	152	0	11	106	71
25	45	3	1	0	0	0	0	0	0	0	0	485	0	0	0	0	0	0	0	86
26	46	3	1	0	0	0	0	0	0	0	0	304	0	0	0	0	0	0	0	78
27	34	4	0	0	0	15	0	28	0	0	42	0	0	318	0	365	0	0	318	78
28	35	4	0	0	15	16	0	29	0	42	43	0	48	309	0	294	0	48	197	78
29	36	4	0	0	16	17	0	30	0	43	44	0	119	320	0	323	0	7	100	78
30	37	4	0	0	17	18	0	31	0	0	0	0	207	183	0	272	0	0	0	79
31	38	4	0	0	18	19	0	32	0	0	0	0	39	162	0	84	0	0	0	79
32	39	4	0	0	19	0	0	33	0	0	47	0	106	0	0	194	0	0	12	79
33	40	4	0	0	0	0	0	34	0	0	48	0	0	0	0	49	0	0	82	79
34	41	4	0	0	0	22	0	35	0	48	49	0	0	86	0	99	0	5	100	78
35	42	4	0	0	22	23	0	36	0	49	50	0	13	73	0	103	0	24	62	78
36	43	4	0	0	23	24	0	37	0	0	51	0	3	103	0	232	0	0	72	79
37	44	4	1	0	0	0	0	0	0	0	0	371	0	0	0	0	0	0	0	79
38	45	4	1	0	0	0	0	0	0	0	0	470	0	0	0	0	0	0	0	86
39	46	4	1	0	0	0	0	0	0	0	0	325	0	0	0	0	0	0	0	81
40	33	5	0	0	0	27	0	41	0	0	55	0	0	93	0	157	0	0	93	78
41	34	5	0	0	0	28	0	42	0	0	56	0	0	217	0	394	0	0	379	78
42	35	5	0	0	0	29	0	43	0	56	57	0	0	141	0	278	0	170	221	78
43	36	5	0	0	0	30	0	44	0	57	58	0	0	312	0	255	0	44	78	78
44	37	5	0	0	30	31	0	45	0	0	0	0	170	373	0	133	0	0	0	79
45	38	5	0	30	31	32	0	46	0	0	0	5	285	202	0	185	0	0	0	79
46	39	5	0	31	32	33	0	47	0	0	61	37	115	138	0	139	8	0	13	79
47	40	5	0	0	33	34	0	48	0	0	62	0	63	46	0	92	0	0	142	78

Figure 24. Sample of STRTFLOW output file contents

****REPORT-MASTER FILE PRINTOUT****
TOTAL NUMBER OF GRIDS ON FILE- 2998
FACTOR TO CONVERT ELEVATION DATA TO METER UNITS--1.000
X,Y DIMENSIONS OF ARRAY IN GRIDS- 53 124
GRID SPACING IN METERS-100.00
TIME INTERVAL FOR FLOW CALCULATION - 0.2000

REC NO	GRID LOC X	GRID LOC Y	CHAN / GRID	RECORD ADDRESS OF NEAREST NEIGHBORS 1	2	3	4	5	6	7	8	XX10 APPORT OF FLOW, USING SLOPE AND LAG FACTOR 1	2	3	4	5	6	7	8	CURVE NO
2	44	1	0	0	0	0	0	3	0	0	0	0	0	0	0	701	0	0	0	71
3	45	1	0	0	0	0	0	4	0	0	0	0	0	0	0	701	0	0	0	71
4	46	1	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	355	0	81
5	39	2	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	833	0	81
6	40	2	0	0	0	0	0	7	0	0	0	0	0	0	0	562	0	0	0	81
7	41	2	0	0	0	0	0	8	0	0	0	0	0	0	0	973	0	0	0	81
8	42	2	0	0	0	0	0	9	0	0	0	0	0	0	0	753	0	0	0	81
9	43	2	0	0	0	0	0	10	0	0	0	0	0	0	0	794	0	0	0	81
10	44	2	0	0	0	0	0	11	0	0	0	0	0	0	0	886	0	0	0	78
11	45	2	0	0	0	0	0	12	0	0	0	0	0	0	0	749	0	0	0	71
12	46	2	1	0	0	0	0	0	0	0	0	743	0	0	0	0	0	0	0	81
13	47	2	0	0	0	0	12	0	0	0	0	0	0	0	1000	0	0	0	0	99
14	34	3	0	0	0	0	0	15	0	0	0	0	0	0	0	1000	0	0	0	78
15	35	3	0	0	0	0	0	16	0	0	0	0	0	0	0	1000	0	0	0	78
16	36	3	0	0	0	0	0	17	0	0	0	0	0	0	0	1000	0	0	0	78
17	37	3	0	0	0	0	0	18	0	0	0	0	0	0	0	708	0	0	0	79
18	38	3	0	0	0	0	0	19	0	0	0	0	0	0	0	667	0	0	0	79
19	39	3	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	280	72
20	40	3	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	639	0	72
21	41	3	0	0	0	0	0	22	0	0	0	0	0	0	0	701	0	0	0	71
22	42	3	0	0	0	0	0	23	0	0	0	0	0	0	0	496	0	0	0	71
23	43	3	0	0	0	0	0	24	0	0	0	0	0	0	0	675	0	0	0	71
24	44	3	0	0	0	0	0	25	0	0	0	0	0	0	0	772	0	0	0	71
25	45	3	1	0	0	0	0	0	0	0	0	971	0	0	0	0	0	0	0	86
26	46	3	1	0	0	0	0	0	0	0	0	608	0	0	0	0	0	0	0	78
27	34	4	0	0	0	0	0	28	0	0	0	0	0	0	0	1000	0	0	0	78
28	35	4	0	0	0	16	0	0	0	0	0	0	0	1000	0	0	0	0	0	78
29	36	4	0	0	0	0	0	30	0	0	0	0	0	0	0	1000	0	0	0	78
30	37	4	0	0	0	0	0	31	0	0	0	0	0	0	0	1000	0	0	0	79
31	38	4	0	0	0	19	0	0	0	0	0	0	0	658	0	0	0	0	0	79
32	39	4	0	0	0	0	0	33	0	0	0	0	0	0	0	708	0	0	0	79
33	40	4	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	281	79
34	41	4	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	609	78
35	42	4	0	0	0	0	0	36	0	0	0	0	0	0	0	647	0	0	0	78
36	43	4	0	0	0	0	0	37	0	0	0	0	0	0	0	973	0	0	0	79
37	44	4	1	0	0	0	0	0	0	0	0	741	0	0	0	0	0	0	0	79
38	45	4	1	0	0	0	0	0	0	0	0	940	0	0	0	0	0	0	0	86
39	46	4	1	0	0	0	0	0	0	0	0	651	0	0	0	0	0	0	0	81
40	33	5	0	0	0	0	0	41	0	0	0	0	0	0	0	759	0	0	0	78
41	34	5	0	0	0	0	0	42	0	0	0	0	0	0	0	1000	0	0	0	78
42	35	5	0	0	0	0	0	43	0	0	0	0	0	0	0	1000	0	0	0	78
43	36	5	0	0	0	30	0	0	0	0	0	0	0	1000	0	0	0	0	0	78
44	37	5	0	0	0	31	0	0	0	0	0	0	0	1000	0	0	0	0	0	79
45	38	5	0	0	31	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	79
46	39	5	0	0	0	0	0	47	0	0	0	0	0	0	0	973	0	0	0	79
47	40	5	0	0	0	0	0	0	0	0	62	0	0	0	0	0	0	0	793	78

Figure 25. Saturated single-nearest-neighbor flow conditions (saturation condition flows are underlined)

CURVE NUMBERS					
LAND USE		HYDROLOGIC SOIL GRP			
CODE	NAME	1	2	3	4
1	ROW CROPS	64	72	79	81
2	CLOSE-GROWING CROPS	70	79	84	88
3	RECREATION AREA	72	81	88	91
4	DOUBLE-CROPPED CROPLAND	65	75	82	86
5	HORTICULTURAL AREA	67	77	83	87
6	GOOD COVER GRASSLAND	62	71	78	81
7	POOR COVER GRASSLAND	70	80	86	90
8	IDLE LAND	55	68	78	83
9	DECIDUOUS FOREST	68	79	86	99
10	CONIFEROUS FOREST	71	79	86	89
11	HARDWOODS/PINE MIXED FOREST	42	66	77	81
12	BRUSHLAND	42	66	77	81
13	OTHER RELATED AGRIC. LAND	42	66	77	81
14	FFEDING OPERATIONS	42	66	77	81
15	NONFARM RURAL LAND	72	82	87	89
16	URBAN RESIDENTIAL	49	69	79	84
17	URBAN COMMERCIAL AND SERVICES	39	61	74	80
18	URBAN INDUSTRIAL	72	79	84	87
19	URBAN OPEN LAND	74	84	90	92
20	PONDS, RIVERS, LAKES, SWAMPS	100	100	100	100

THE MEAN FLOW LENGTH PER GRID IS 370.2 FEET

TIME INTERVAL FOR THE CALCULATIONS IS 0.1000 HOUR

Figure 26. Curve number, mean flow length, and time interval tabular output from STRTFLOW

b. Mean Flow Length and Time Interval. The mean flow length ℓ calculated using Equation 10 and the time interval for which the flow allocation is prepared are also tabulated (Figure 26) to provide a permanent copy.

c. Channel Grid Map. A printer-produced map of the watershed is provided (Figure 27) locating all grids through which a channel flows. Figure 27 shows the upper left section of the watershed for a 200-m grid spacing. The column and row location of each grid is indicated by the sequential numbers appearing along the top and left side of the map, respectively. A series of 8's are used to designate grids outside the watershed, 0's for nonchannel grids within the watershed, and 1's for channel grids within the watershed. Figure 27 was reproduced from the 200-m grid so that the general shape of the watershed and the channel flow pattern would be discernible to the reader. The map is very distorted since the horizontal-to-vertical scale ratio is approximately five to one.

163. The map data are used to locate flow information for specific channel grids in the output data base tabulation such as the one shown in Figure 24, and vice versa. The output data base information for each grid contains the XY-(row and column) number identifiers shown in Figure 27.

a. Curve Number Grid Map. Figure 28 shows a similar grid map using the curve numbers.

b. Output Data Base. The result of the STRTFLOW flow allocation network calculation is output to a file for use in the storm flow calculation. The data are randomly written onto the file, with each record containing all data required for the flow calculation for a single grid. The very first record written on the file contains certain control information, such as the file size and storm time increment to be used automatically in setting up and proceeding through the flow calculations. The tabular output, which shows the data in the file, is provided with a heading to make the data more readable. The information above the tabular heading is contained in the first record of the output file. The data below the tabular heading are contained in successive sequential records. Inspection of the tabular output shows all the features described above. A visual inspection of Figure 24 or 25 shows the following:

(1) The record number (random location of the data in the file and the sequence identification numbers

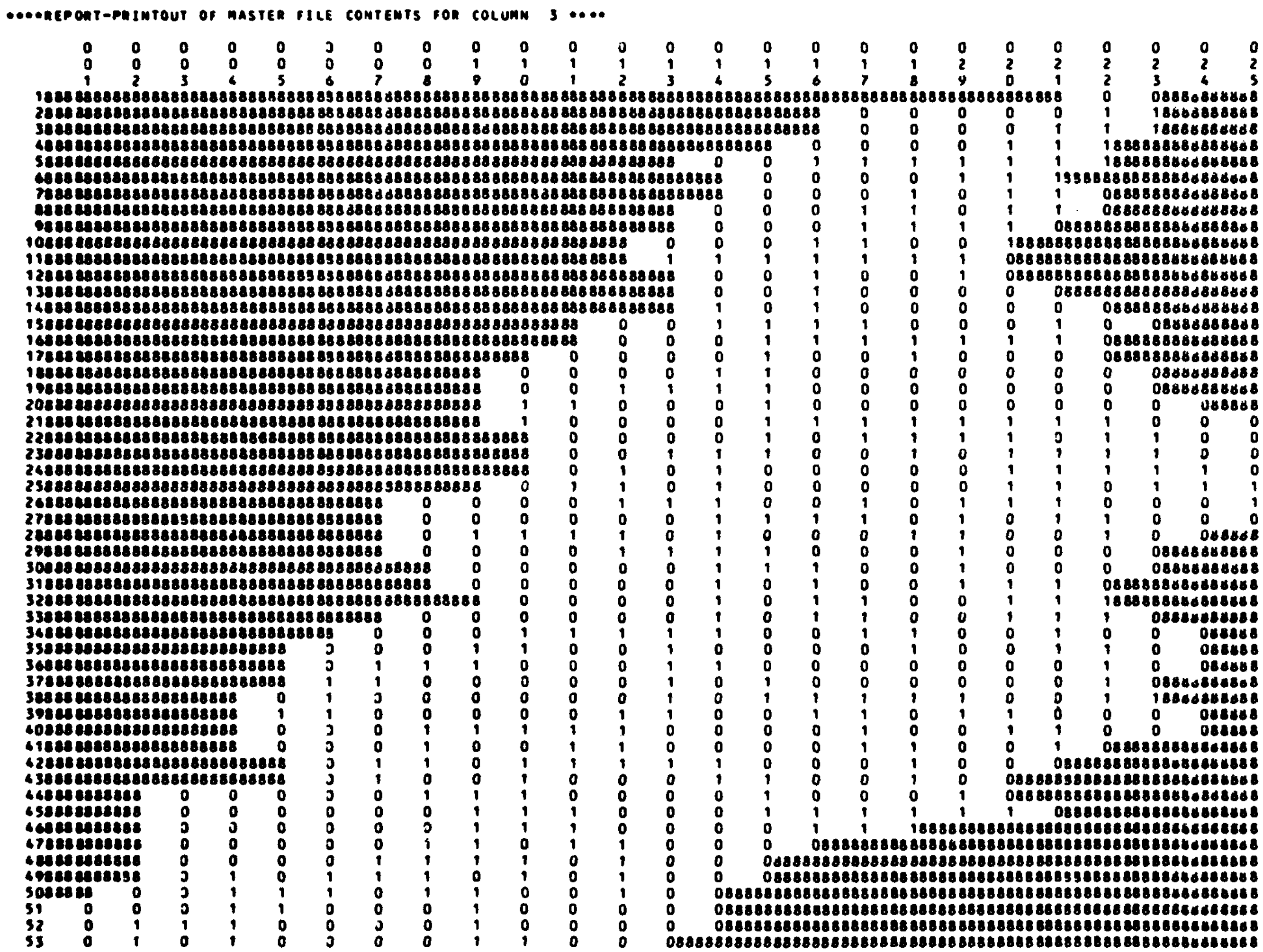

Figure 27. Printer map of channel grids

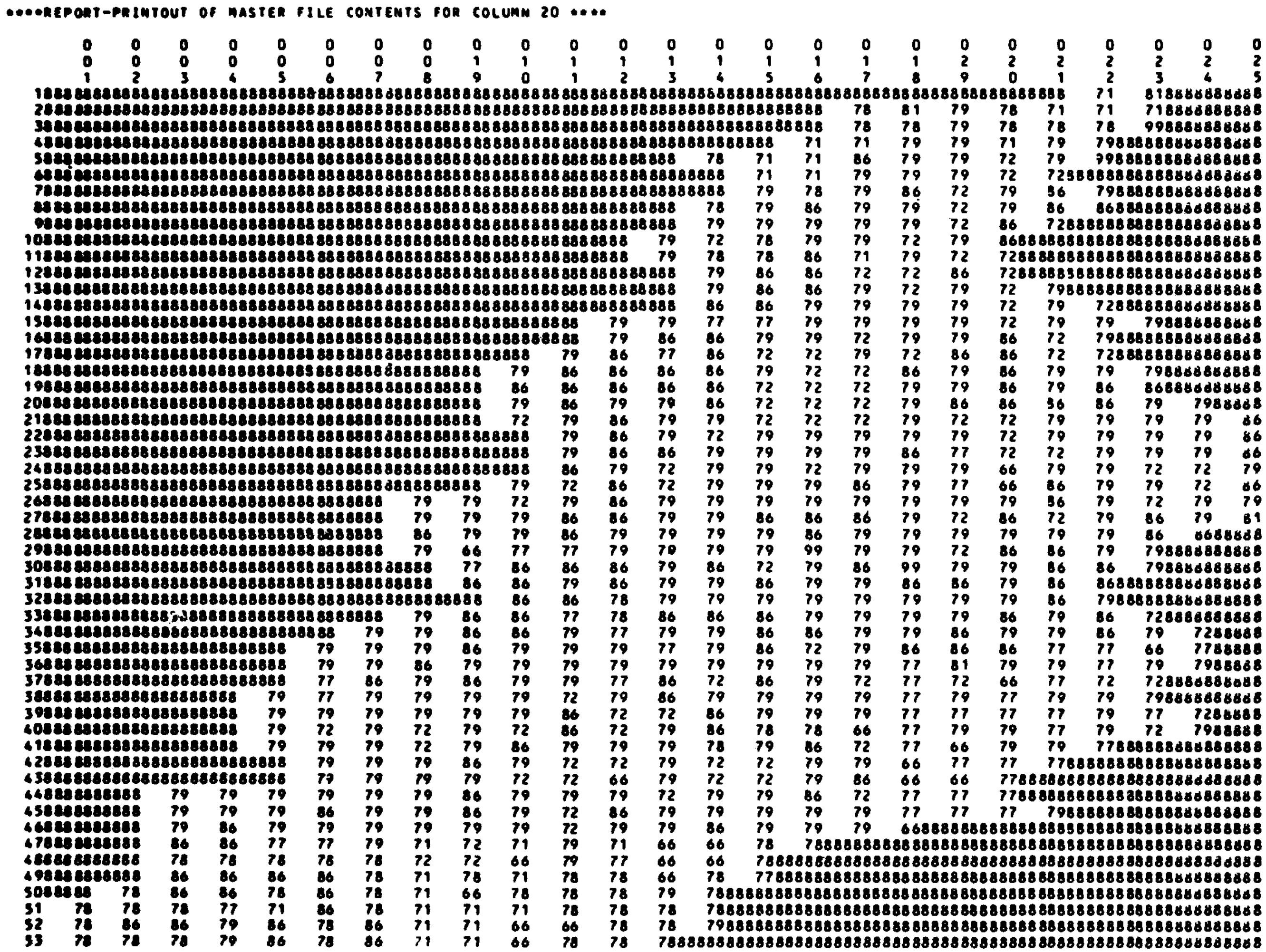

Figure 28. Printer map of curve numbers

for each grid) increases sequentially.

(2) The data are ordered by Y, and by X for the same value of Y. It should be remembered that a reflected Cartesian coordinate system is used in the grid coordinate system. The position (1,1) is at the upper left corner of the watershed map. The X coordinate increases in value to the right, and the Y coordinate increases in value down the map.

(3) Grids containing channels have a "1" in the fourth output column.

(4) The "Record Address of Nearest Neighbors" lists, for each grid, the sequence numbers of all nearest neighbors to which the grid flows; the "% Apportionment of Flow, Using Slope and Lag Factor" provides the flow apportionment values for those nearest neighbors. For example (see Figure 24), grid sequence number 20 with X,Y coordinates (40, 3) apportions its flow as follows: 1.8% to grid sequence number 7, 5.1% to grid 19, 4% to grid 21, 0.2% to grid 32, 8.7% to grid 33, and 6% to grid 34.

(5) The curve number for each grid is shown in the last column.

<u>Summary</u>

164. STRTFLOW sets up the rules for rainfall runoff flow allocation and provides those rules in a file. The output file has a structure designed to minimize the time required to track a storm through the watershed.

Surface Flow

165. The surface flow calculation is performed by the program FLOW. The flow calculations are performed in an identical manner independent of the time increment, the rainfall intensity, or the grid spacing. The following sections describe the rainfall data use, how the runoff components--direct rainfall and cross-grid flow--are handled, and how the calculation is terminated.

166. As shown in Figure 22, the program DRAIN is used to calculate effective areas and curve numbers for grids prior to operating FLOW. It is necessary to delay the discussion of effective areas and curve

numbers until after a discussion of FLOW so as to maintain continuity with the presentation in the previous section. Since the system is so interconnected, with calculations from STRTFLOW, FLOW, DRAIN, and HYDRO meshing into one another, it would be helpful to the reader to reread this section on surface flow after completing the remainder of this chapter.

Rainfall

167. A graph of the rainfall intensity function used in this study is shown in Figure 21. The same figure also contains a tabulation of the rainfall intensity for a 0.05-hour time interval. The tabulation is a listing of the rainfall data file input to FLOW. The first record (line 10000) is used to inform FLOW that the time increment is 0.05 hour and the total cumulative rainfall is 2 in. The succeeding records (lines 10001-10041) contain successively incremented time values and the rainfall amplitudes (in arbitrary units) at those time values read from the graph.

168. Rainfall data files for the 0.10- and 0.20-hour time increments were also prepared by retaining the 0.10- and 0.20-hour increment data values shown in the 0.05-hour file.

169. FLOW always assumes that the rainfall intensity is zero at $t = 0$, i.e.,

$$Q^R(0) = 0 \tag{15}$$

where $Q^R(t)$ is the cumulative rainfall to time t . The cumulative rainfall is calculated from the input data by cumulating and normalizing the rainfall function to the total rainfall:

$$Q_I^R(t) = Q^T \frac{\sum_{k=1}^{J} Q_k^A}{\sum_{J=1}^{II} Q_J^A} \tag{16}$$

where

$Q_I^R(t)$ is the cumulative rainfall on Grid I to time t

$t = (J - 1)\,\Delta t$, Δt = time increment

Q^T is the total cumulative rainfall

Q_J^A is the rainfall intensity at the $J^{\underline{th}}$ time interval

II is the number of increments required for the rainfall intensity to return to a zero amplitude

170. FLOW reads all of the Q_J^A values from the input data base and ceases reading when no more input values are encountered. Note that the use of Q_{IJ}^A is not warranted at this time since the system presently assumes a uniform rainfall distribution.

171. Another required input to FLOW is the maximum length of time T_M that the flow calculation proceeds before its automatic termination. As described in the next section of this report, the calculation is terminated after this length of time if it has not previously been automatically terminated by the program's sensing of a reduction in the water flow amplitude to a small value.

172. The cumulative rainfall record is continued out to the time T_M :

$$Q_I^R\,(t)\Big|_{t = (II-1)\Delta t,\ T_M} = Q^R\,[(II-1)\Delta t] \qquad (17)$$

Therefore, if the incremental rainfall does not reduce to a zero value at the end of the input rainfall record, FLOW forces it to zero over the time interval $(II-1)\Delta t$ to T_M . This should always happen since the length of time over which the calculation will be allowed to proceed is always longer than the length of the input rainfall record, due to the runoff time lag. The effect on the calculation results of not making this T_M large enough is covered in the description of HYDRO and its normalization operations.

<u>Flow</u>

173. The flow calculation tracks and provides a time history for

two flow components for each grid. The two flow components are the non-infiltrated rainfall (i.e., the direct rainfall runoff) in temporary storage and the water that has flowed from other grids onto, and is now in temporary storage on, the grid. The term "temporary storage" is used to imply that all of the water in such a storage condition will ultimately flow, through other grids if necessary, to the collection channels. It is necessary to remember the time history of both components for erosion calculation use. It is also convenient to recover both components from the calculation since the calculations are quite different within FLOW.

174. The reader should remember that <u>cumulative</u> values are followed through the flow calculation for convenience.

175. The temporary cumulative storage quantity that has been in storage on a grid from $t = 0$ until time t is $Q_I(t)$:

$$Q_I(t) = Q_I^S(t) + Q_I^F(t) \tag{18}$$

where $Q_I^S(t)$ is the component of the cumulative flow contributed by direct rainfall and $Q_I^F(t)$ is the component contributed by cumulative flow from other grids, both of which have gone into temporary storage on grid I during the time interval $(t - \Delta t)$ to t for all time increments up to t .

176. Note that $Q_I(t)$ is the cumulative amount that has been in storage and that by time t much of the quantity that had been in storage will have flowed off the grid. The quantity in storage at time t is

$$Q_I(\Delta t) = Q_I(t) - Q_I(t - \Delta t) \tag{19}$$

or the difference in cumulative amount in storage from beginning to end of the calculational time increment. Naturally,

$$Q_I(\Delta t) = Q_I^S(t) - Q_I^S(t - \Delta t) + Q_I^F(t) - Q_I^F(t - \Delta t) \tag{20}$$

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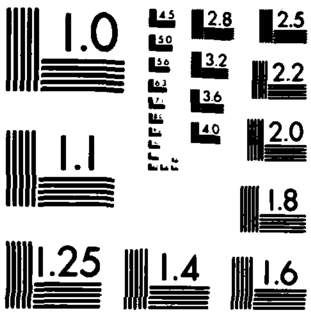

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177. The cumulative rainfall to time t is $Q_I^R(t)$ as defined in Equation 16. The rainfall runoff (not cumulative) that becomes part of cumulative temporary storage, due to direct rainfall, at time t is then

$$Q_I^S(\Delta t) = \left[(Q_I^R(t) - 200.0)/CN_I + 2.0\right]^2 \Big/ \left[(Q_I^R(t) + 800.0)/CN_I - 8.0\right] - Q_I^S(t - \Delta t) \qquad (21)$$

where

$Q_I^S(\Delta t)$ is the contribution from rainfall during time t to the temporary rainfall storage on grid *I*

CN_I is the grid curve number

178. $Q_I^S(t-\Delta t)$ is the cumulative direct rainfall component in temporary storage at $t - \Delta t$. Therefore

$$Q_I^S(t) = Q_I^S(t - \Delta t) + Q_I^S(\Delta t) \qquad (22)$$

The iterations in the calculation start at time $t = \Delta t$, not at time $t = 0$. The value of $Q_I^S(t - \Delta t)$ for $t = \Delta t$, is

$$Q_I^S(0) = 0 \qquad (23)$$

by inference, since the rainfall distribution was defined so that

$$Q_I^R(t) = 0 \Big|_{t = 0} \qquad (24)$$

This mathematical assumption provides a very convenient starting point for the calculation.

178. The rainfall abstraction term is readily recognizable in the initial squared term in Equation 21. If the value of this term is less than or equal to zero, the contributed component is set to zero; i.e., if

$$(Q_I^R(t) - 200)/CN_I + 2.0 \leq 0 \tag{25}$$

where CN_I is the curve number for grid I, then

$$Q_I^S(\Delta t) = 0 \tag{26}$$

since that rainfall is totally lost to infiltration.

180. The quantity $Q_I^S(\Delta t)$ is added to the cumulative temporary storage on grid I due to direct rainfall runoff, so that in simple form

$$Q_I^S(t) = \sum_{L=1}^{N} Q_I^S(\Delta t)\bigg|\, t = N\Delta t \tag{27}$$

forms the general expression.

181. The rainfall over the grid I is assumed spatially uniform, so that some of the rainfall runoff on grid I is allowed to follow the normal runoff network for that grid during the time interval in which it fell. Once runoff originating from direct rainfall leaves a grid, it becomes part of the grid-to-grid network flow and is accounted for in the Q_I^F component of flow. The grid-to-grid flow relationship for grid I is as follows:

$$\begin{aligned} Q_I^F(t) = Q_I^F(t - \Delta t) &+ \sum_{k=1}^{8} \left[Q_k^S(t) - Q_k^S(t - \Delta t)\right] \frac{L_I^k}{\Delta t} \\ &- \left[Q_I^F(t - \Delta t) - Q_I^F(t - 2\Delta t)\right] \sum_{k=1}^{8} \frac{L_k^I}{\Delta t} \\ &+ \sum_{k=1}^{8} \left[Q_K^F(t - \Delta t) - Q_k^F(t - 2\Delta t)\right] \frac{L_I^k}{\Delta t} \\ &+ \left[Q_I^S(t) - Q_I^S(t - \Delta t)\right] \left(1.0 - \sum_{k=1}^{8} \frac{L_k^I}{\Delta t}\right) \end{aligned} \tag{28}$$

182. The notation of Equation 28 is changed from previously used notation to simplify the form of the equation. An inspection of Equation 14 shows that the term L_I^k is used in Equation 28 as a replacement for the lag term, so that $L_I^k/\Delta t$ is the flow allocation rule for the surrounding eight nearest neighbors to grid I used to specify the flow from grid k to grid I.

183. It is convenient to note the convention used in Equation 28, namely, that the flow is from the grid that is the upper index L_I^{k} (the k index) to the nearest grid that is the lower index L_{I}^k (the I index). The reader should also note that the flow allocation values are in units that must be multiplied by 0.001 as described in paragraph 147.

184. The index k is used as a dummy summation index. If there is no flow from the k^{th} to the I^{th} grid, then $L_I^k = 0$. The reader *should remember that* $L_I^k = 0$ for seven of the eight k values for every I for the single-nearest-neighbor flow allocation case. Otherwise the single-nearest-neighbor is identical with the eight-nearest-neighbor flow calculation.

185. Equation 28 contains five terms. In sequential order, these terms are as follows:

a. Term 1. The cumulative grid-to-grid flow in temporary storage on the I^{th} grid at the beginning of any time interval.

b. Term 2. The direct rainfall runoff from the k nearest-neighbor grids that flows onto grid I during the time interval and becomes part of grid I's grid-to-grid flow component.

c. Term 3. The grid-to-grid flow on grid I at the start of the time interval that flows to other grids during the time interval.

d. Term 4. The grid-to-grid flow from the k grids, available in temporary storage on the k grids at the start of the time interval, that flows onto grid I during the time interval.

e. Term 5. That portion of the direct rainfall runoff on grid I during the time interval that remains on the grid after part has flowed off to surrounding k nearest-neighbor grids.

186. The time order of the third and fourth terms and the lack of

higher order terms should be noted in Equation 28. These terms are the highest order used because of the assumption that the flow from a grid does not totally cross over nearest-neighbor onto second- (and further) nearest-neighbor grids in the time interval Δt . As previously stated in another fashion, the exclusion of higher order terms from the calculations was done to make the solution financially tractable.

187. Finally, the analog to Equation 22 for the grid-to-grid flow component is

$$Q_I^F(t) = Q_I^F(t - \Delta t) + Q_I^F(\Delta t) \tag{29}$$

which shows quite simply how the cumulative is formed.

Computer File Structure

188. The mathematical procedure implementation requires several arrays to be maintained in computer memory.

189. The rainfall time history function, $Q^R(t)$ in Equation 16, is stored for the total length of the calculation.

190. The cumulative direct rainfall runoff component of the flow $Q_I^S(t)$ and the cumulative grid-to-grid component of the flow $Q_I^F(t)$ values are temporarily maintained in memory for each grid within the watershed. At the beginning of the flow calculation during a time increment Δt , the $Q_I^S(t)$ and $Q_I^F(t)$ values are those attributed to the grids for the previous time increment. At the calculation initiation (i.e., at $t = \Delta t$) both arrays are zero since no rain has fallen. The $Q_I^S(t)$ and $Q_I^F(t)$ values at the end of the flow calculations during a time increment Δt are the values attributed to that grid at that time $t + \Delta t$, and the values for the previous time t are <u>replaced</u> with the values for the successive time increment. At the end of the calculation for a time increment over the entire watershed, the $Q_I^S(t)$ and $Q_I^F(t)$ are written out to a file, so that a complete time history of the flow components is available for the storm and flow histories.

191. The changes in the flow components during Δt are maintained in another array. At the start of a time increment, the cumulative rainfall required for Equation 21 is available in the rainfall data

file. Direct rainfall runoff in grid I is directly distributed to the nearest-neighbor flow network, and the remainder goes into temporary storage on grid I. Therefore, there is no need to maintain a running time account for $Q_I^S(\Delta t)$. Equation 28 requires remembering flows in temporary storage at the start of the time increment in order to evaluate the third and fourth terms. This requirement is handled by maintaining two arrays in memory. At the start of the time increment, one array contains the temporary flow available for grid-to-grid flow distribution, and the other array is set to zero. As FLOW progresses through the watershed array grid by grid, the temporary storage value for a given grid I in array 1 is distributed to the appropriate array 2 nearest-neighbor grid locations according to the network distribution of the I grid. The remainder of the temporary storage that did not flow to neighboring grids is left in the array 2 location for grid I, so that the value for grid I in array 1 can be set to zero. At the completion of one pass through the watershed, the calculation for that time increment is completed and arrays 1 and 2 interchange meanings. This reveals another specific (and probably financially most important) statement of the necessity for limiting Equation 28 to the time order terms it contains. Namely, if N is the time order increment in the calculation, a total of N! passes through the entire watershed (one flow calculation allocation set of calculations for each grid) must be performed for each time increment.

Flow Cutoff

192. As the flow for a specific grid is allocated during the FLOW operation, any neighboring grid to which no flow is allocated is ignored. The water volume allocated to a grid sooner or later decreases, after the storm completion, to a value that becomes negligible and can be ignored. A decision was made to ignore an allocation if the value dropped below 0.0001 in. Results, cumulative and incremental, reviewed to the fourth decimal place, were not affected by this decision. The penalty for not providing such a cutoff rule is that the calculation time for any given watershed on different computers is a strong function of the computer word size.

193. As the storm progresses through its time history, FLOW calculates all allocation path flows for all watershed grids. Shortly after the storm ends, the flow volumes of those grids with small drainage areas decrease rapidly. The effect of the flow cutoff rule is that a smaller and smaller number of calculations is performed at each time interval starting shortly after the storm completion as more and more flow allocations are terminated.

Alternate Math Approaches

194. The mathematically adroit reader might, about this time, wonder why a tensor arithmetic approach was not used in the flow calculation because of the readily recognizable form of Equation 28 and the indirect reference to indices contraction in paragraph 183. It is impossible to perform the calculation in closed form; an iterative, computer-based method must be followed, forcing the calculation to be performed along lines following the description provided in this report. Therefore, alternate and equally valid mathematical descriptions, while aesthetically more pleasing, are not as useful.

Calculation Termination

195. It is necessary to continue the flow calculation so that the flow history of all grids of interest is complete. It is also necessary to terminate the flow calculation at some reasonable point in time. Since the flow amplitude for any grid decreases slowly by increments, the failure to provide a termination decision rule would result in abnormally long computer calculations. It is important to remember that the flow time relationships for different grids can be significantly different. That is, the flow for one grid within the watershed may have effectively terminated while the maximum flow amplitude for another grid has not yet been reached. Depending on the purpose of the calculation, any number of grids at any random locations within the watershed can be monitored automatically by FLOW during the flow calculation, and the calculation terminated when the flow in those grids decreases below a set threshold. This capability is set up and accomplished in the following manner.

196. Data input to the flow calculation include two times, T_C

and T_M . T_M was previously described as the maximum length of time that the flow history will be followed by FLOW. T_C is the time at which the flow calculation starts to automatically monitor the flow amplitudes through the selected grids. The amplitude of the rainfall duration relation shown in Figure 21 reduces to zero after 2 hours. T_C was arbitrarily set to 2 hours since it is practically impossible, unless an excessive value for t is used, for any grid's flow to approach zero immediately after the storm's cessation. The rule used for terminating the flow calculation is as follows: terminate if

$$\frac{Q_I^F (t) - Q_I^F (t - \Delta t)}{Q_I^f (t)} < 0.0001 \qquad (30)$$

197. Since this condition cannot be met, particularly for grids with large lags, until long after $Q_I^S(t)$ approaches zero, this condition is equivalent to one based on $Q_I(t)$, the sum of the flow componants. The choice of T_C as the approximate time of the storm cessation makes this calculation termination rule insensitive to the most extreme rainfall variation in conditions of flow path complexity.

198. The flow history for each grid is normalized using another computer program described in the last section of this part, entitled "Flow Time History Results." To avoid errors, the area under the truncated flow curve, or the total cumulative flow at the cutoff time, must have a value close to the untruncated value. Since the shape of a flow curve can vary significantly from one grid to the next, it is not possible to derive an absolute cutoff rule. The option followed in the Equation 30 procedure was to select such a small amplitude cutoff rule and thus move the truncation point so far out onto the tail of the flow curve, that truncation would not affect the area calculation results until the third or fourth significant digit on grids with large flow amplitudes and lags.

199. The grids that are monitored are selected after calculating the effective drainage areas and curve numbers with program DRAIN (see

Figure 22). This calculation is described in the next section of this report. The grid X,Y coordinates are input to FLOW, and FLOW provides an output report. A sample of this output report is shown in Figure 29 for a $t = 0.05$-hour calculation. In Figure 29, only four grids were monitored, and a report on each grid is provided at the end of each time interval calculation. Note that the direct rainfall surface flow has ended prior to 2.4 hours so the cumulative value has stabilized (column 5 in Figure 29); the first derivative of this parameter is zero from at least 2.4 hours onward. The grid-to-grid surface flow component is still changing, however, until the calculation is truncated at $t = 2.7$ hours.

Flow Calculation Output

200. The FLOW calculation produces a flow history data base for the watershed. That data base contains, for each Δt, the flow data for every grid in the watershed. Specifically, the data base contains three pieces of information for each grid: the cumulative direct rainfall runoff $Q_I^S(t)$, the cumulative grid-to-grid flow components $Q_I^F(t)$, and the amount in temporary storage at time t $Q_I^F(\Delta t)$.

201. This file is input to program HYDRO, as shown in Figure 22.

				SURFACE WATER FLOW FOR SELECTED GRIDS		
				SURFACE FLOW, CU FT		
	RAINFALL		GRID	SOURCE		
TIME HOUR	INCREM	CUMUL	SEQUNC, NO	RAIN	FLOW	TOTAL
0.05	0.001	0.00	2448	0.	0.	0.
0.05	0.001	0.00	2449	0.	0.	0.
0.05	0.001	0.00	2450	0.	0.	0.
0.05	0.001	0.00	2451	0.	0.	0.
0.80	0.120	1.15	2448	0.0877	0.7023	0.7900
0.80	0.120	1.15	2449	0.0877	0.5345	0.6222
0.80	0.120	1.15	2450	0.0877	0.3384	0.4261
0.80	0.120	1.15	2451	0.0877	0.2106	0.2983
0.85	0.120	1.27	2448	0.1252	1.1311	1.2563
0.85	0.120	1.27	2449	0.1252	0.8534	0.9786
0.85	0.120	1.27	2450	0.1252	0.5457	0.6709
0.85	0.120	1.27	2451	0.1252	0.3318	0.4569
0.90	0.120	1.39	2448	0.1678	1.7086	1.8764
0.90	0.120	1.39	2449	0.1678	1.2861	1.4539
0.90	0.120	1.39	2450	0.1678	0.8289	0.9967
0.90	0.120	1.39	2451	0.1678	0.4909	0.6587
2.40	0.	2.00	2448	0.4482	31.0359	31.4841
2.40	0.	2.00	2449	0.4482	34.1797	34.6279
2.40	0.	2.00	2450	0.4482	34.0514	34.5996
2.40	0.	2.00	2451	0.4482	20.7440	21.1922
2.45	0.	2.00	2448	0.4482	31.1214	31.5695
2.45	0.	2.00	2449	0.4482	34.4185	34.8666
2.45	0.	2.00	2450	0.4482	34.5102	34.9533
2.45	0.	2.00	2451	0.4482	21.1820	21.6301
2.50	0.	2.00	2448	0.4482	31.1904	31.6385
2.50	0.	2.00	2449	0.4482	34.6183	35.0665
2.50	0.	2.00	2450	0.4482	34.8972	35.3453
2.50	0.	2.00	2451	0.4482	21.5711	22.0193
2.55	0.	2.00	2448	0.4482	31.2460	31.6942
2.55	0.	2.00	2449	0.4482	34.7849	35.2331
2.55	0.	2.00	2450	0.4482	35.2291	35.6773
2.55	0.	2.00	2451	0.4482	21.9147	22.3629
2.60	0.	2.00	2448	0.4482	31.2909	31.7391
2.60	0.	2.00	2449	0.4482	34.9234	35.3716
2.60	0.	2.00	2450	0.4482	35.5125	35.9607
2.60	0.	2.00	2451	0.4482	22.2163	22.6645
2.65	0.	2.00	2448	0.4482	31.3272	31.7753
2.65	0.	2.00	2449	0.4482	35.0381	35.4863
2.65	0.	2.00	2450	0.4482	35.7532	36.2014
2.65	0.	2.00	2451	0.4482	22.4795	22.9277
2.70	0.	2.00	2448	0.4482	31.3564	31.8046
2.70	0.	2.00	2449	0.4482	35.1329	35.5811
2.70	0.	2.00	2450	0.4482	35.9570	36.4051
2.70	0.	2.00	2451	0.4482	22.7080	23.1561

Figure 29. Sample FLOW output report on monitored grids

Effective Drainage Areas and Curve Numbers

202. The computer program DRAIN provides a straightforward calculational procedure used to arrive at effective drainage areas and curve numbers for every grid in the watershed. The calculation assumes a steady-state saturated flow condition and follows the flow allocations until the flow networks are defined on the landscape. The object is to define the flow networks in terms of effective drainage areas and curve numbers for each grid.

203. The assumption of a steady-state saturated flow is a vehicle for simplifying the calculation as much as possible without <u>any</u> decrease in accuracy compared to other possible but much more complex procedures. Because of this assumption, the calculation becomes time independent and can terminate when the flow pattern stabilizes.

204. The calculation follows a procedure similar to that shown in Equation 28.

205. All grids are preloaded with a unit rainfall (i.e., a value of 1.0). The convenience of this is realized by understanding that the inferred volume is then one grid area × 1.0 for each grid, so that when the stabilized flow condition is reached, the cumulative flow values for the grids are directly interpretable as the effective drainage areas for the grids.

206. Since the calculation is independent of time, the flow allocation algorithm reduces to the following simple form:

$$A_I(P) = A_I(P - 1) + \sum_{k=1}^{8} \frac{A_k(P - 1)L_I^k}{\sum_{J=1}^{8} L_J^k} \tag{31}$$

where

$A_I(P)$ is the effective drainage area of grid I after P calculation iterations

P is the dummy index for passes through the watershed grids

$A_k(P)$ is the effective drainage area of the k nearest-neighbor grid to the I grid

L_I^k is the flow allocation rule for flow from grid k to grid I

L_J^k is the flow from the k grid to all its nearest neighbors

Equation 31 uses the abbreviated notation of Equation 28.

207. At $P = 1$, the value of $A_I(0) = 1.0$, the area of the grid I, since the unit rainfall values are preloaded into the watershed array.

208. The $A_I(P)$ is the effective drainage area of the I^{th} grid where the calculation has proceeded to and completed pass number P through the watershed. In each pass through the watershed, each grid in the watershed is considered sequentially as it appears in the file, and the final value for the effective area of grid I, A_I is achieved when the flow stabilizes; i.e., at that P value for which the following condition holds:

$$A_I = A_I(P) \left| \frac{dA_I}{dP} \simeq 0 \right. \qquad (32)$$

where the differential of the iterative drainage area approaches zero. The flow allocation to grid I comes from its nearest neighbors (dummy variable k in Equation 31). Since the flow allocation values output by STRTFLOW and used by DRAIN are functions of t, the time effect is removed by normalizing the flow from each of the surrounding k nearest neighbors.

209. In practice, as each grid is considered in turn by DRAIN, the flow allocation for that grid is first normalized, i.e.,

$$\frac{L_I^k}{\sum_{J=1}^{8} L_J^k} \qquad (33)$$

and the normalized flow values used to allocate the effective area accumulated up to that P pass. In understanding Equation 32, it helps to first visualize the Equation 33 normalization taking place, and then to visualize this term in Equation 32.

210. The effective curve number for each grid is calculated simultaneously with the effective area in a two-step process. The first part of the process is the following:

$$CN_I(P) = CN_I(P - 1) + \sum_{k=1}^{8} \frac{CN_k A_k(P - 1) L_I^K}{\sum_{J=1}^{8} L_J^k} \tag{34}$$

where $CN_I(P)$ is the cumulative area-weighted product of the curve numbers and the drainage areas having those curve numbers that contribute to flow onto grid I, with a value acquired by pass P through the watershed

CN_k is the curve number of the k^{th} grid

211. At the completion of the calculation, the effective curve number $\overline{CN}_I$ for grid I is calculated by completing the area-weighting calculation, i.e.,

$$\overline{CN}_I = \frac{CN_I(P)}{A_I(P)} \bigg| \frac{dA_I}{dP} \simeq 0 \tag{35}$$

<u>Channels</u>

212. Channel grids play the same role in the DRAIN flow calculation as they do in the FLOW flow calculation. If a grid contains a channel, the flow into the grid goes into the channel and is not allocated to other grids. Every grid has its own area included within its effective area.

<u>Stability</u>

213. The calculation stops when stability is achieved. "Stability" is best defined by a description of the calculation strategy. It would be possible to arrive at a stable flow by using an artificial storm input that has a constant rainfall intensity and extends out in time until further flow iterations on the grids do not change the flow amplitude, i.e., the first derivative becomes zero. The desired

solution would be the asymptotic limit of the flow calculation. This approach was circumvented by calculating the asymptotic limit directly. The approach used was to place unit rainfall on each grid at the start of the calculation as previously mentioned, assume no loss of water during flow, and calculate the amount, in grid units of water that flowed through each grid on the way to the channels. Stability, using this strategy, is the condition when no grids retain water, or alternatively, when all water has reached the channels. The effective drainage area of a grid is then the cumulative water volume that has passed over that grid.

214. DRAIN calculates for each successive pass the percent of the watershed that has not reached stability and provides the information in an output report (Figure 30). DRAIN contains an interval cutoff threshold of fifty passes; this threshold can be changed if required. If stability is not achieved before tripping the threshold, the calculation terminates. Figure 30 shows that the 100-m-grid-spaced model of the watershed with an eight-nearest-neighbor flow pattern required 25 passes before reaching stability. The number of required passes is a function of the maximum flow path length in the watershed model. Obviously, the single-nearest-neighbor flow pattern stabilizes much faster (15 passes) than the eight-nearest-neighbor flow pattern for the same watershed model.

215. A different threshold is applied to the flow allocation calculation for each grid to provide a convenient cutoff for those calculations. As DRAIN performs the Equation 31 calculation for each grid, if the quantity

$$\frac{A_k(P - 1)L_I^k}{\sum_{J=1}^{8} L_J^k} < 0.000001 \tag{36}$$

then that component of the routing is set to zero.

216. The results calculated using this threshold were found

```
*****************************************************************
                  PROGRAM DRAIN OPERATION REPORT
*****************************************************************
   100.00 PERCENT OF GRIDS FLOWED IN THIS PASS
    96.56 PERCENT OF GRIDS FLOWED IN THIS PASS
    93.23 PERCENT OF GRIDS FLOWED IN THIS PASS
    89.73 PERCENT OF GRIDS FLOWED IN THIS PASS
    85.26 PERCENT OF GRIDS FLOWED IN THIS PASS
    80.15 PERCENT OF GRIDS FLOWED IN THIS PASS
    73.25 PERCENT OF GRIDS FLOWED IN THIS PASS
    65.24 PERCENT OF GRIDS FLOWED IN THIS PASS
    57.27 PERCENT OF GRIDS FLOWED IN THIS PASS
    48.80 PERCENT OF GRIDS FLOWED IN THIS PASS
    39.26 PERCENT OF GRIDS FLOWED IN THIS PASS
    29.59 PERCENT OF GRIDS FLOWED IN THIS PASS
    21.71 PERCENT OF GRIDS FLOWED IN THIS PASS
    14.44 PERCENT OF GRIDS FLOWED IN THIS PASS
     9.11 PERCENT OF GRIDS FLOWED IN THIS PASS
     4.97 PERCENT OF GRIDS FLOWED IN THIS PASS
     2.97 PERCENT OF GRIDS FLOWED IN THIS PASS
     2.10 PERCENT OF GRIDS FLOWED IN THIS PASS
     1.73 PERCENT OF GRIDS FLOWED IN THIS PASS
     1.27 PERCENT OF GRIDS FLOWED IN THIS PASS
     0.73 PERCENT OF GRIDS FLOWED IN THIS PASS
     0.37 PERCENT OF GRIDS FLOWED IN THIS PASS
     0.17 PERCENT OF GRIDS FLOWED IN THIS PASS
     0.03 PERCENT OF GRIDS FLOWED IN THIS PASS
     0.   PERCENT OF GRIDS FLOWED IN THIS PASS
    25 PASSES WERE REQUIRED
```

Figure 30. Report on progress of the flow stability calculation

identical to the results without the threshold in at least the first 5 significant digits. The effect of this threshold is to speed up the calculations and make the calculation effort independent of computer word size and cost-predictable from one computer to another. The increase in speed, typically yielding an approximate 30 percent reduction in calculation time, has a small influence on the number of passes required for stabilization but primarily influences the number of calculations during a pass.

217. This aforementioned threshold (Equation 36) is specifically the reason for the condition $dA_I/dP \simeq 0$ shown in Equations 32 and 35.

Output

218. At the completion of the calculation, DRAIN produces a data

file containing the channel/no channel designator, effective drainage area, and effective curve number for each grid in the watershed. DRAIN also produces grid maps showing the data values.

219. The channel/no channel output map is identical to the map output by STRTFLOW; an example was previously shown in Figure 27.

220. Examples of the effective area and curve number maps are shown in Figures 31 and 32 for the 200-m, eight-nearest-neighbor flow pattern calculation. These maps show the actual data available in the DRAIN output file. Note that the area and curve number values are multiplied by 1000 and rounded prior to output so that the values are available to the third decimal place.

221. Various uses of these data have been described. As a specific example of such a use, the reader should look back to Figure 29, which shows the report for the grids monitored during, and used to terminate, the flow operation. The monitored grids in Figure 29 were sequence numbers 2448, 2449, 2450, and 2451. In choosing the grids to be monitored, a map such as that shown in Figure 31 was inspected to locate grids with large effective drainage areas. The drainage area is directly related to the lag, and therefore to the shift of the flow curve to longer times. The X,Y coordinates of the grids selected for monitoring were input to FLOW, which automatically located those grids in its data file, noted their sequence numbers, and keyed them for monitoring.

222. The digital data file output by DRAIN, and its use in the flow curve normalization (see Figure 22), is another principal objective of using the DRAIN program. This use is explored in the next section of this report.

```
****REPORT-PRINTOUT OF MASTER FILE CONTENTS FOR COLUMN 4 ****

    001 002 003 004 005 006 007 008 009 010 011 012 013 014 015 016 017 018 019 020 021 022 023 024 025
 1 1689 1636
 2 1000 2490 4226 4835 3562 2677 3516
 3 1127 2077 2894 3506 5327 2168 1000
 4 1315 1000 1684 1585 2395 2511 1000
 5 1000 1450 2068 2554 2128 4124 1348 1000 1000
 6 1631 2422 2432 3928 2904 1340 2801
 7 1542 2751 3609 3689 1286 1342 1536 1801
 8 1034 1498 2426 3604 1168 1000 1231 1427 1337
 9 1000 1576 2404 2935 1263 1183 1009 1000
10 1033 1552 2333 3152 2144 1296 1279 1070
11 1336 2325 2212 4773 7946 2087 2806 1079
12 1010 1575 2036 8659 1659 1893 1701
13 1000 1383 1943 6682 2598 2414 1831 1437
14 1348 1462 1734 3585 2572 2142 1693 1444 1167
15 1161 1982 2520 2174 1341 2728 2661 2481 1767 2597 1443 1000
16 1327 2252 3249 3788 1584 1568 3185 4650 3317 3043 1536
17 1052 1436 2158 2978 4396 1630 1258 2087 2755 2795 2246 1008
18 1000 1052 1777 2223 2767 4283 2956 1809 1282 1189 1070 1220 1207 1000
19 1378 2275 3093 4421 2710 7417 2945 2594 1201 1074 1239 1891 2301 1498
20 1564 2768 2660 2278 2231 2513 3221 2253 1685 1677 2464 4269 3586 1785 1003
21 1110 1206 1288 1421 2009 3259 1379 1720 1726 2625 4737 4963 4263 2650 1493 1000
22 1000 1202 1577 2027 2910 1653 1804 1664 1581 1990 1000 1913 5531 2894 1050
23 1091 2456 2952 3270 3118 1578 1468 1631 1554 1579 1019 1000 4254 4392 3754
24 1631 2363 1842 3176 2435 1482 1006 1046 1257 1735 1410 1296 1530 3826 3451
25 1285 1864 1702 1000 3031 2101 1380 1011 1000 1352 1714 1878 1415 2160 3228 1054
26 1000 1093 1126 1334 1670 1457 3455 2111 1450 1141 1325 2241 2216 1949 1628 1506 2113 1584
27 1321 2212 2229 1900 1747 1545 3463 2014 1356 3316 1550 2075 1952 2261 3172 1739 1213 1187
28 1815 5345 4002 3366 2571 1670 1905 1553 1100 1026 1811 2125 1526 1911 4157 1623 1000
29 1119 1359 1836 2420 3523 4577 3028 1796 1518 1410 1136 2706 1531 1182 1793 1609
30 1000 1374 1983 3066 5081 6450 1804 4791 2823 1132 2440 1956 1544 1156 1000
31 1035 1660 2563 3355 5918 3139 1185 1383 1465 1115 1941 2159 1862 1019
32 1588 2262 2568 3586 2827 1151 1023 1761 1000 1382 1814 1326 1564
33 1772 1493 1454 1905 2170 2210 2676 1464 1110 1589 1011 1099 3353 2046 2139 1700
34 1205 1393 3306 3569 2138 2635 4022 3101 1873 1205 1237 1782 1366 2192 2816 2303 1409 1063
35 1000 1242 1936 3539 2658 1575 1998 3416 2742 2005 1408 1170 1482 1208 1370 3557 4297 2349 1156
36 1155 2365 2726 2383 1397 1327 1862 3920 3032 2310 1906 1542 1200 1000 1001 1983 3764 1726 1000
37 1890 2178 1461 1164 1331 1834 2506 5436 2038 4201 2920 2475 1917 1375 1000 1191 2003 1146
38 1000 1479 1039 1030 1101 1394 1975 3298 3751 1982 1840 1996 4134 2052 2974 2046 1327 2948 2912
39 1144 1519 1230 1547 1925 2106 2237 3179 2589 1780 1796 1719 2904 1804 2911 3629 2069 1939 2593 1377
40 1000 1505 2230 4490 2373 2462 2728 2550 1986 1403 1380 1217 1157 1457 1804 2238 2691 1389 1083 1000
41 1000 1523 2672 3270 1028 1554 1677 2126 1667 1399 1291 1084 1141 2271 1546 1409 1800 1000
42 1743 3130 1368 1175 2356 2756 3034 2296 2578 2145 1222 1000 2879 1306 1000 1088
43 1642 2446 1320 1221 2889 1826 1536 1768 2977 4048 1768 1083 1005 1125 1674
44 1000 1013 1023 1083 1392 1808 2206 2352 1877 1393 1214 1600 3691 2594 1596 1000 1011 2794
45 2122 2374 1608 1174 1453 2378 2355 1477 2757 1734 1174 1198 2299 1861 1238 1228 2971 2848 1000
46 1109 609811134 1664 1211 1556 2469 1415 3741 2838 1953 1279 1467 2585 1225 1000
47 1014 1412 17861374410518 9409 1401 1179 1409 5271 2733 1628 1000 1001
48 1000 1214 1249 1617 2924 3935 1402 1548 1460 5953 3910 2603 1392
49 1475 2455 1580 2015 2203 2146 1300 1391 1633 5014 3230 1348 1000
50 1192 1843 3198 1065 2449 2281 2539 2482 1360 1823 5359 3924 1048
51 1000 1301 2127 3187 2780 2054 1642 2023 5431 2254 1585 2285 2329 1601
52 1153 2074 1853 2986 1941 1492 1411 1655 2821 3496 1933 1641 1350 1110
53 1367 2660 1000 1846 1636 1256 1200 1587 3542 6030 2639 1300 1000
```

Figure 31. Example of DRAIN effective drainage area map

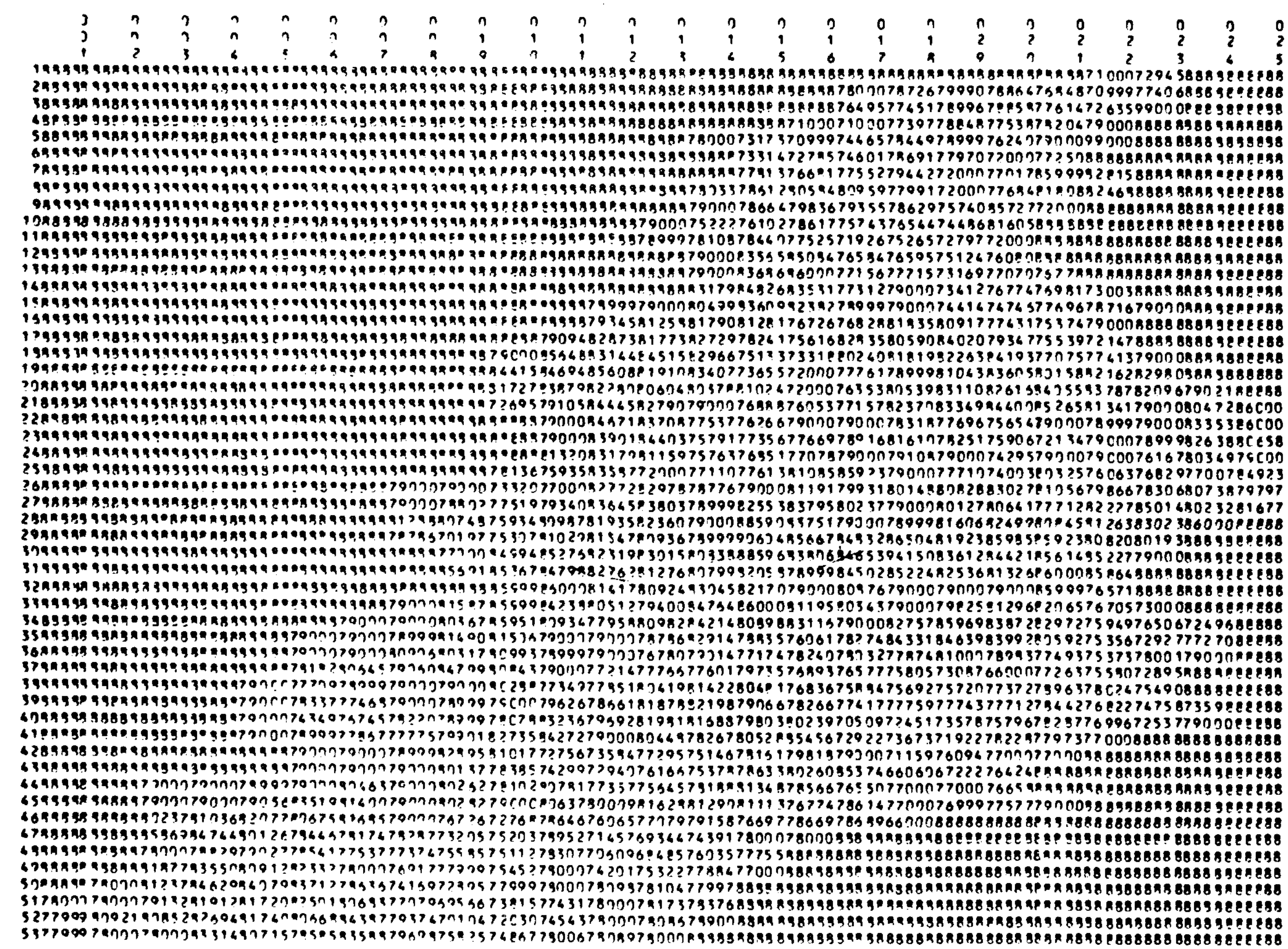


Figure 32. Example of DRAIN effective curve number map

Flow Time History Results

223. The data output by program FLOW are in a form, and in units, convenient for the flow calculation. The program HYDRO sorts data for individual grids selected for output, changes the units, normalizes the flow results, and produces tabular and graphic results.

Grid Selection

224. Any number of grids can be selected for inclusion in the output report. The grids are named by providing their X,Y grid coordinates as input to HYDRO. The coordinates of grid locations can be measured from any maps used in preparing input data or by locating the required data on grid maps, such as the one shown in Figure 27, that are provided in output reports of STRTFLOW, FLOW, and DRAIN. When grid coordinate locations are measured from some map used for data preparation, such as the map shown in Figure 15, it is necessary to perform a simple transformation to calculate the grid coordinates from the measurements. The following is a convenient algorithm for use:

$$X_G = \frac{(X_M - X_{UL})S_M}{D} + 1.0$$

$$Y_G = \frac{(Y_{UL} - Y_M)S_M}{D} + 1.0 \qquad (37)$$

where

X_G, Y_G are the grid coordinates

X_M, Y_M are the coordinates of the location for which grid coordinates are needed

X_{UL}, Y_{UL} are the coordinates of the upper left corner of the geographic region bounding the watershed

S_M is a conversion factor from the units used to metres

D is the grid spacing in metres

The following notes further describe the use of the transformation:

a. The measurement of X_M, Y_M, X_{UL}, and Y_{UL} must be performed with the same units. Any units are acceptable.

b. The transformation is for use with measurements in a normal (not reflected) Cartesian system. The $(Y_{UL} - Y_M)$ performs the reflection needed to calculate the grid coordinates in the required reflected Cartesian system.

c. The X_{UL} and Y_{UL} must be measured at the upper left corner location of the map used in the FLOW location. These data are available in the output report from program COMBDATA and other programs used after COMBDATA.

d. The values of X_G and Y_G must be rounded off to provide integer grid values.

225. Program HYDRO locates the data for the required grids and provides a report such as the one shown in Figure 33. The sequence

LIST OF GRIDS WITH DIRECT REPORTED RESULTS

SEQUENC NUMBER	COORDINATES ARRAY X	ARRAY Y	NORMAL X	NORMAL Y	CHANEL	DRAINAGE AREA,GRD X1000	WEIGHTED CNX1000
1317	18	59	277400	3876200	0	1131	86000
1318	19	59	277500	3876200	0	2270	85274
1325	26	59	278200	3876200	0	14697	85614
1331	32	59	278800	3876200	1	7362	77814
1342	43	59	279900	3876200	0	10269	84041
1355	27	60	278300	3876100	0	28155	80410

Figure 33. List of grids in the HYDRO report

number in Figure 33 is the grid identification number in the FLOW calculation output file. The grid array and normal coordinates are grid coordinates (as input) and the absolute coordinates (as calculated by HYDRO) of the grid in the geographic information system. (Since the UTM coordinate system was used for the study watershed, the normal coordinates in Figure 33 are UTM coordinates.) The channel/no channel designator in the sixth column has the same meaning as previously described. The drainage area and weighted curve number values of the grids are automatically retrieved from the DRAIN output and given in the last two columns of the report.

Data Retrieval and Processing

226. Program FLOW produces for every grid in the watershed a listing of the cumulative flow components, the direct rainfall, and the grid-to-grid flow and repeats this complete listing for every time increment. The sequence numbers in Figure 33 are the locations for the grids' data in sequential data sets for sequential time increments. HYDRO locates the sequential time data for each selected grid, converts the measurement units, normalizes the flow curves, and produces the computer-printed tabular and computer-plotted graphic results as shown in Tables 9-26 and Figures 34-51, respectively.

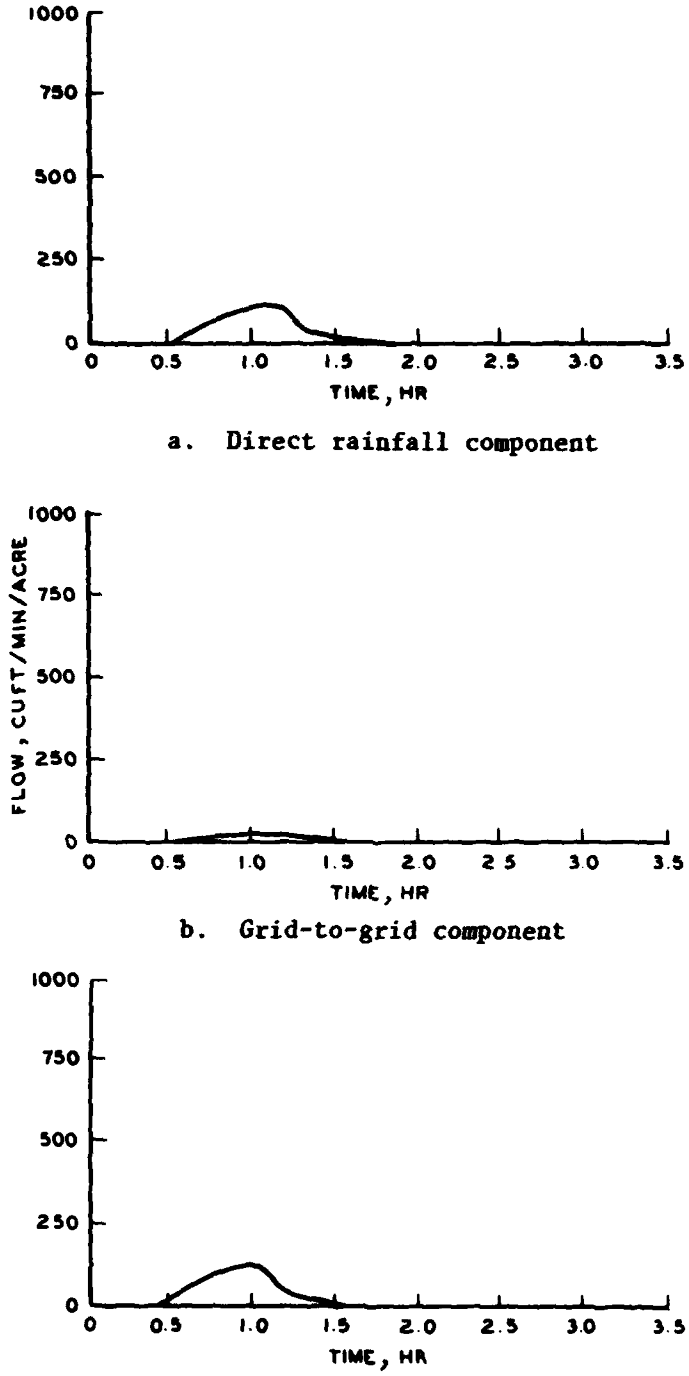
227. The units used in all FLOW calculations are inches/grid/time interval. The conversion factor to cubic feet/minute/acre is as follows:

$$\frac{(3.281\ \text{ft/m})^2\ (\text{grid increment, m})^2}{(12.0\ \text{in./ft})\ (\Delta t\ \text{hours})\ (60.0\ \text{min/hr})\ (2.47105 \times 10^{-4}\ \text{acre/ft}^2)}$$

228. The normalization of the flow curves was discussed in several prior locations in this report. In summary, normalization is performed to alleviate any computer word truncation problems that might be encountered (a) due to the computer used for calculations or (b) because the system is used for watersheds with very low relief. It is also performed to partially, if not totally, correct problems that could arise due to termination of the early flow calculation, particularly for long effective lag grids. The normalization procedure performed independently for each grid is described in the following paragraphs:

229. Equation 21 is used over the total storm time, with the total storm cumulative rainfall, to calculate the total runoff Q_I^N for each grid. The curve number used in the equation is the effective curve number for the drainage area, and the result is multiplied by the grid drainage area. That is,

$$Q_I^N = A_I^E\, Q_I^E \Big|_{CN_I = CN_I^E} \tag{37}$$

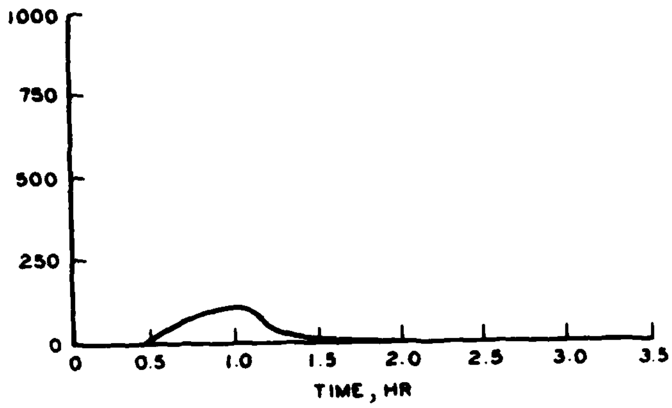


a. Direct rainfall component

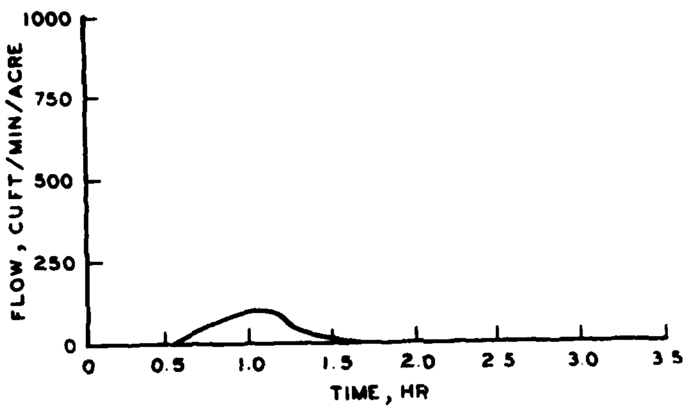
b. Grid-to-grid component

c. Total flow

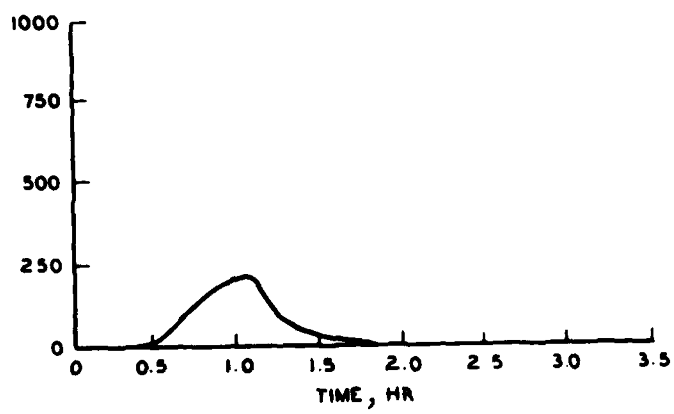
Figure 34. Surface flow, grid sequence 1317, time increment 0.05 hour



a. Direct rainfall component

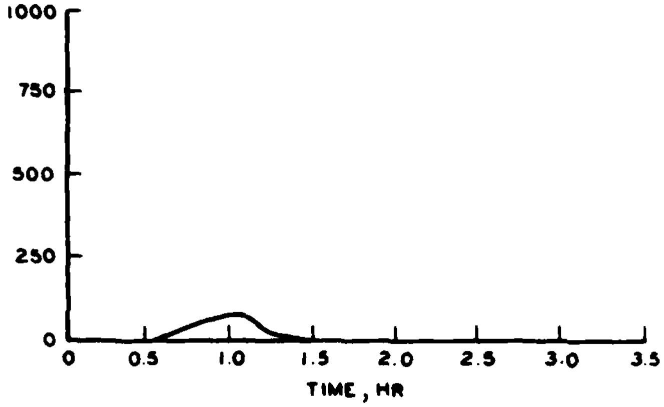


b. Grid-to-grid component

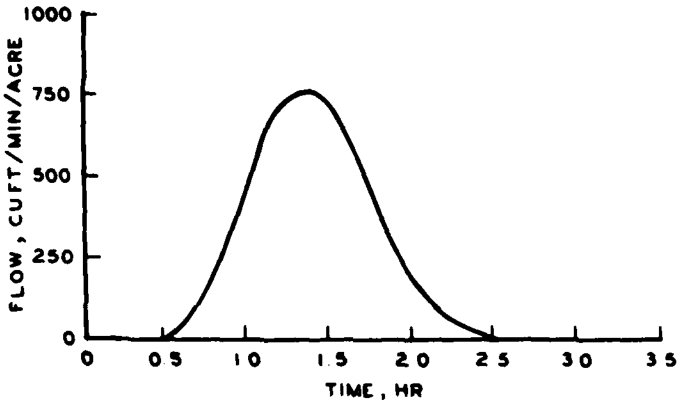


c. Total flow

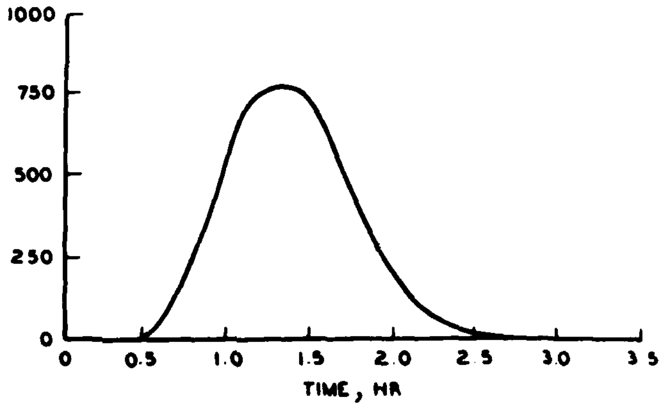
Figure 35. Surface flow, grid sequence 1318, time increment 0.05 hour



a. Direct rainfall component

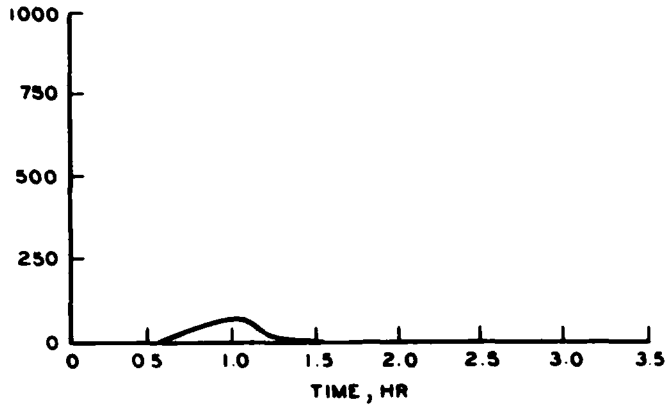


b. Grid-to-grid component

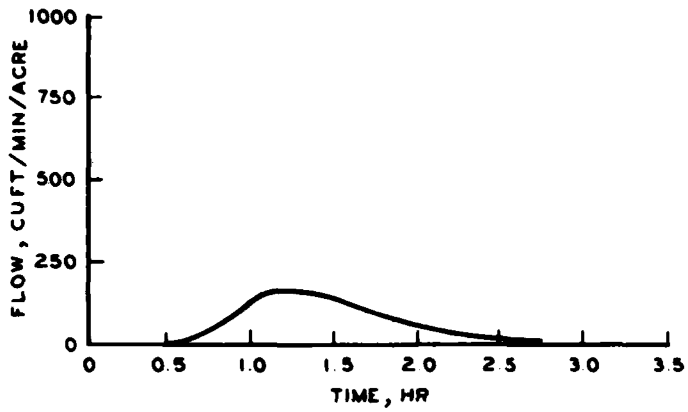


c. Total flow

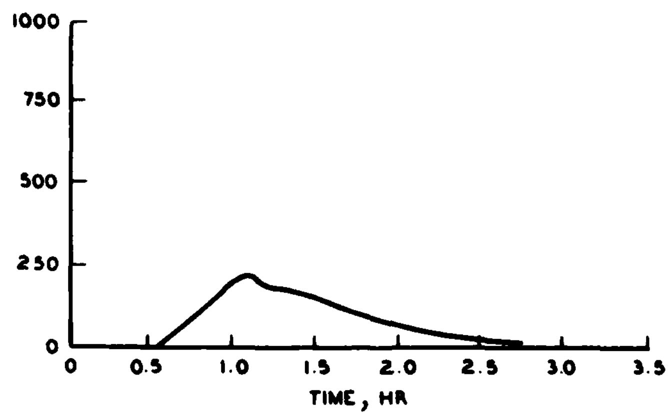
Figure 36. Surface flow, grid sequence 1325, time increment 0.05 hour



a. Direct rainfall component

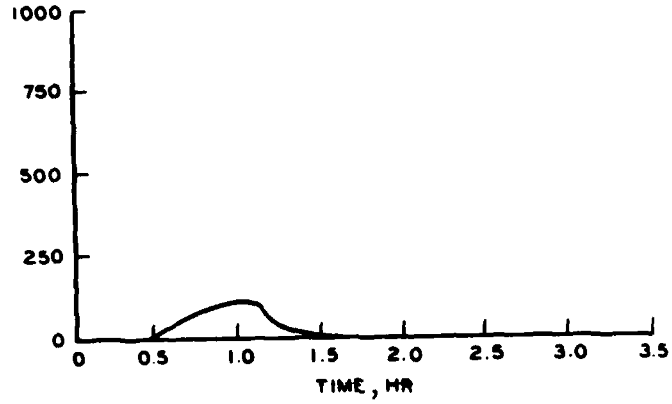


b. Grid-to-grid component

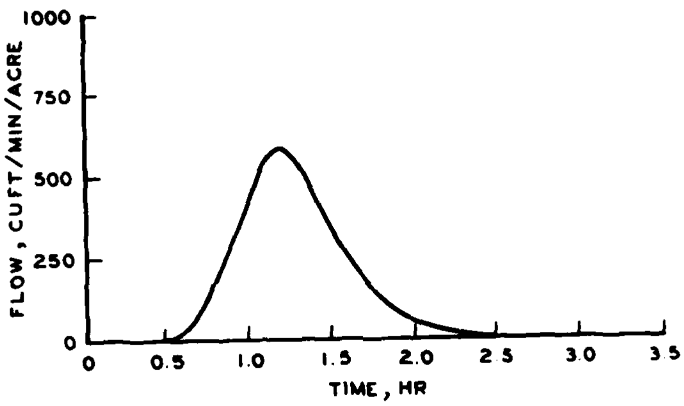


c. Total flow

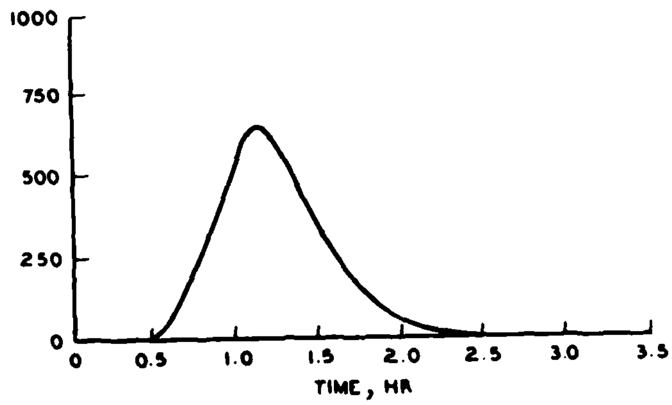
Figure 37. Surface flow, grid sequence 1331, time increment 0.05 hour



a. Direct rainfall component

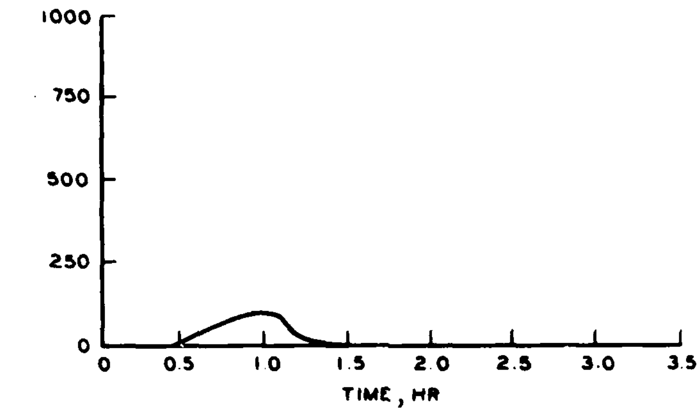


b. Grid-to-grid component

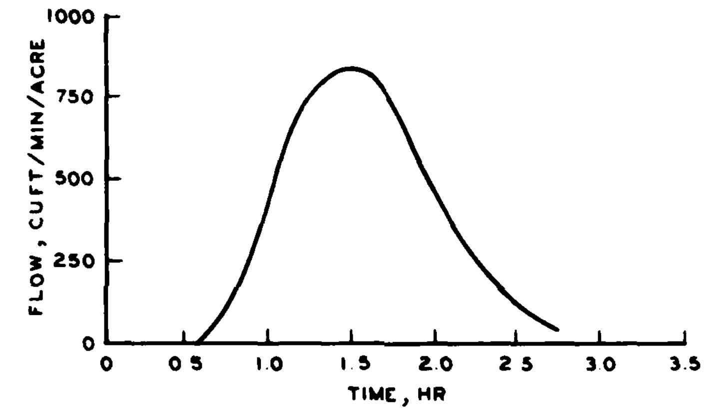


c. Total flow

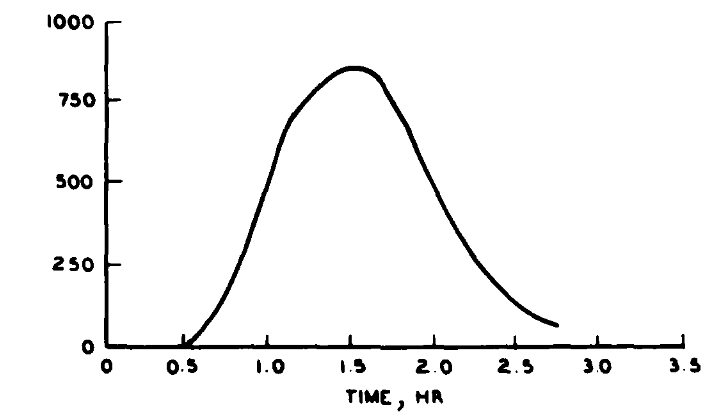
Figure 38. Surface flow, grid sequence 1342, time increment 0.05 hour



a. Direct rainfall component

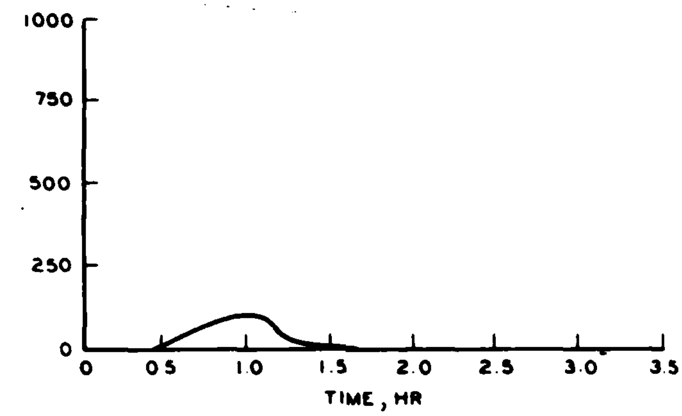


b. Grid-to-grid component

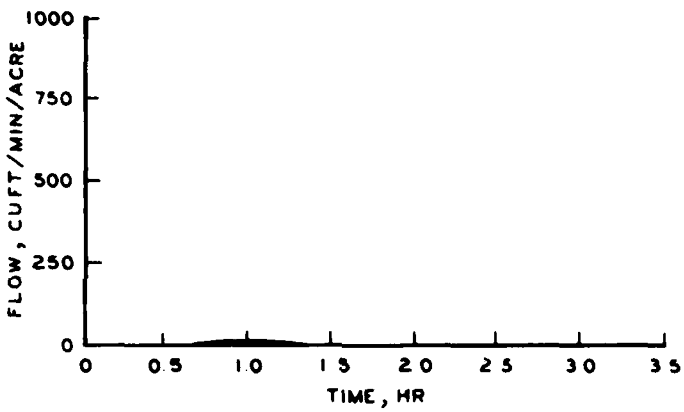


c. Total flow

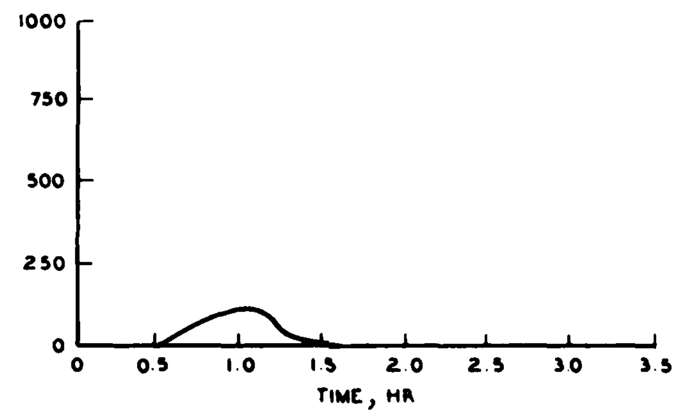
Figure 39. Surface flow, grid sequence 1355, time increment 0.05 hour



a. Direct rainfall component

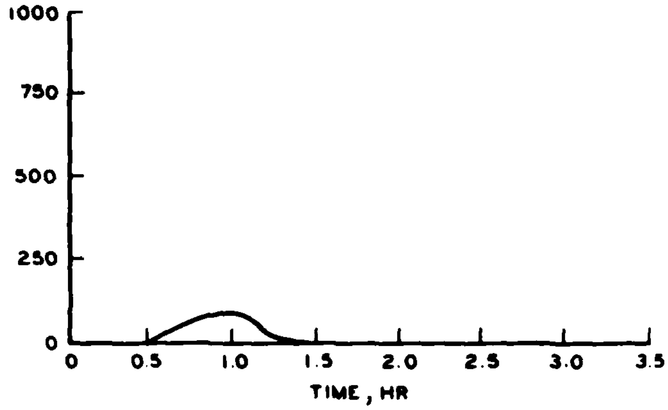


b. Grid-to-grid component

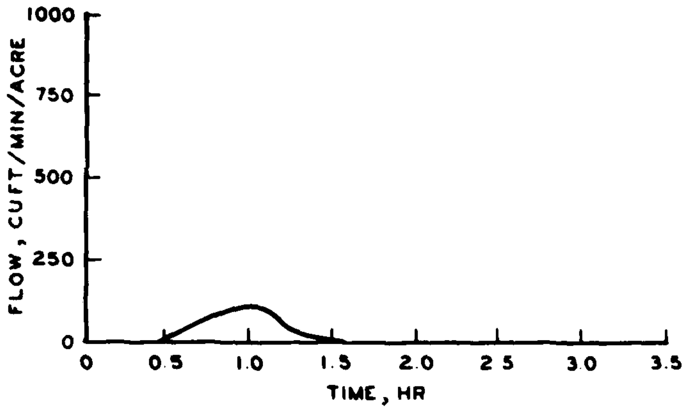


c. Total flow

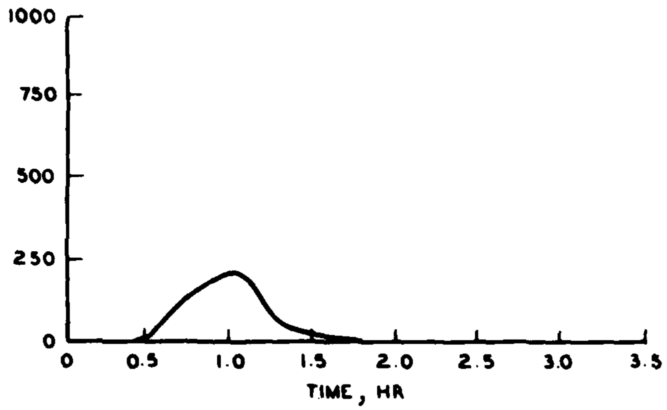
Figure 40. Surface flow, grid sequence 1317, time increment 0.10 hour



a. Direct rainfall component

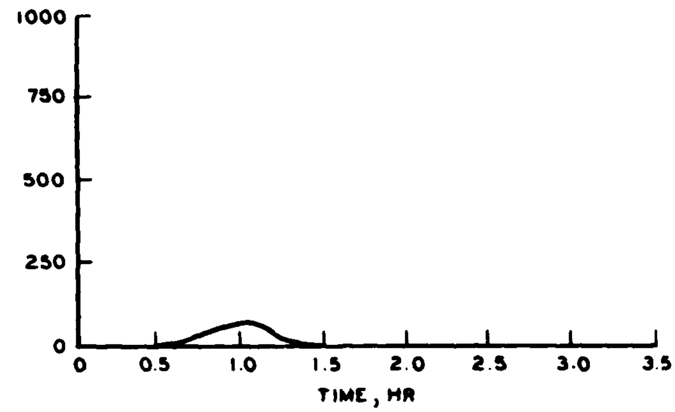


b. Grid-to-grid component

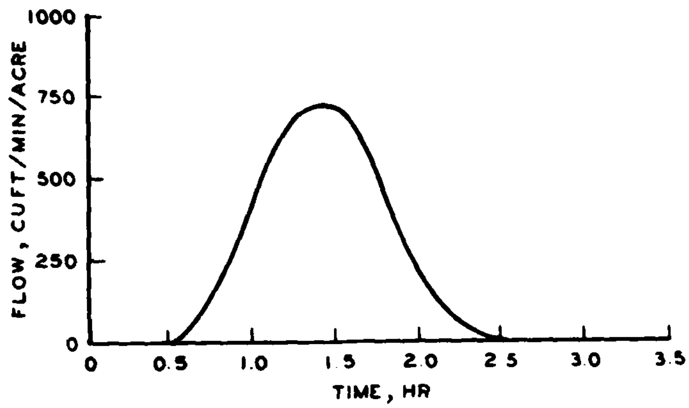


c. Total flow

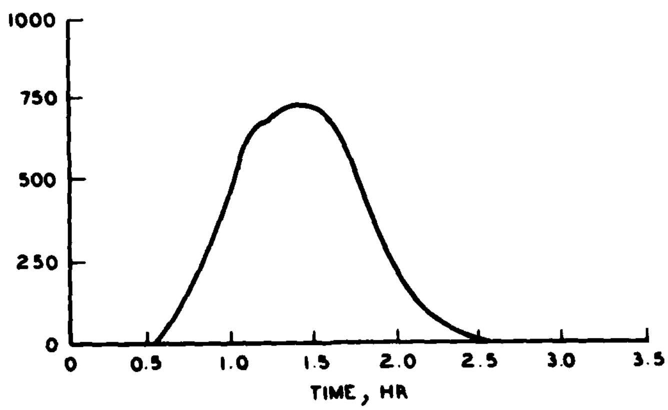
Figure 41. Surface flow, grid sequence 1318, time increment 0.10 hour



a. Direct rainfall component

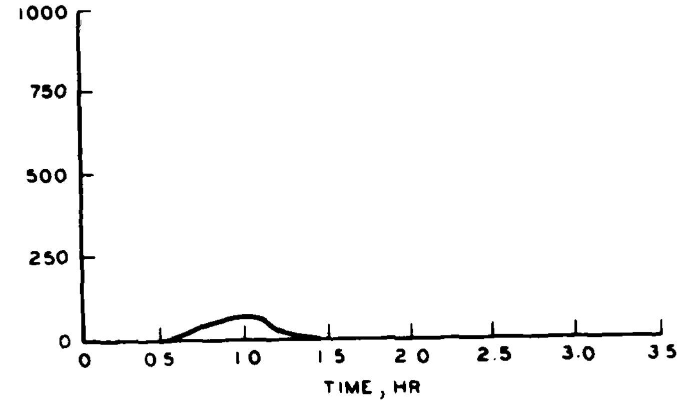


b. Grid-to-grid component

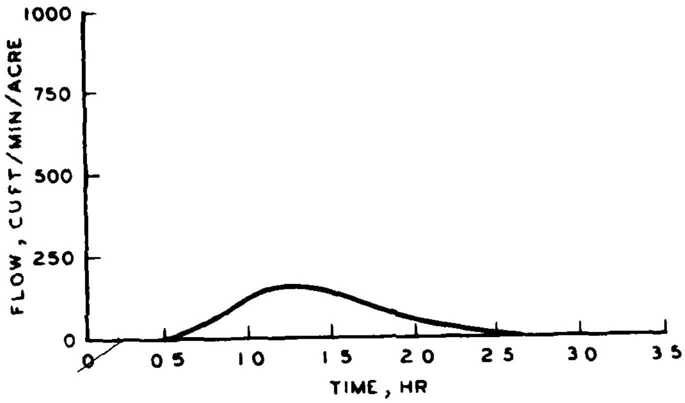


c. Total flow

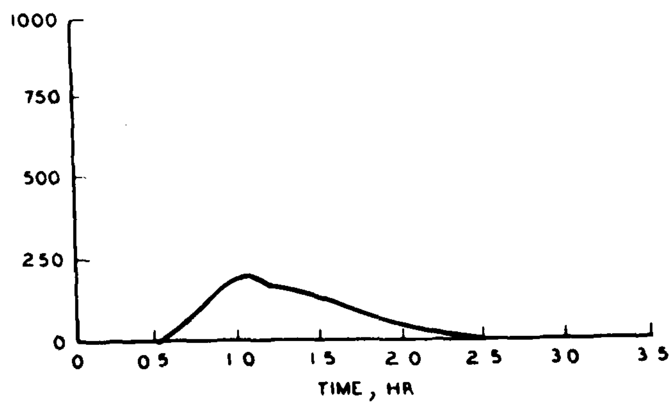
Figure 42. Surface flow, grid sequence 1325, time increment 0.10 hour



a. Direct rainfall component

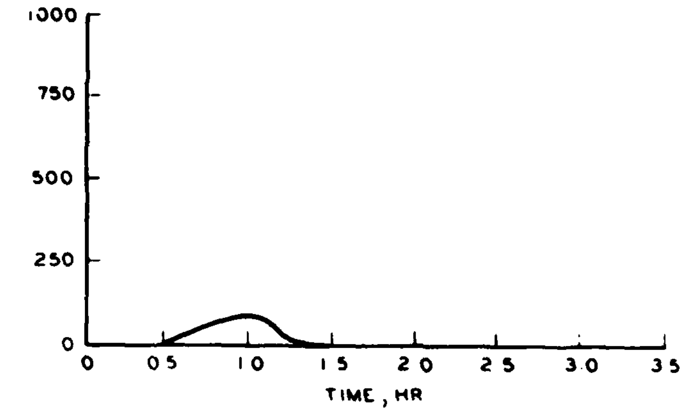


b. Grid-to-grid component

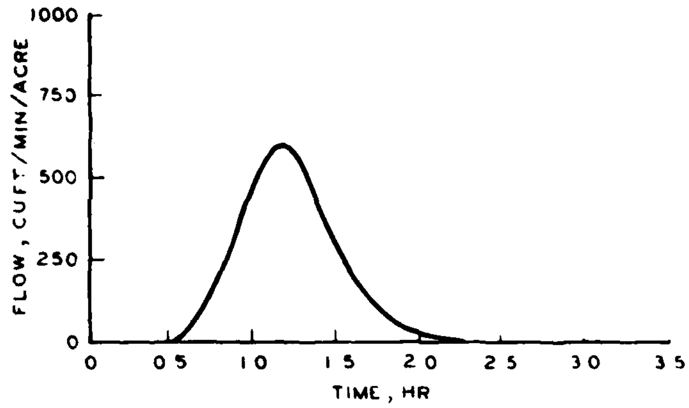


c. Total flow

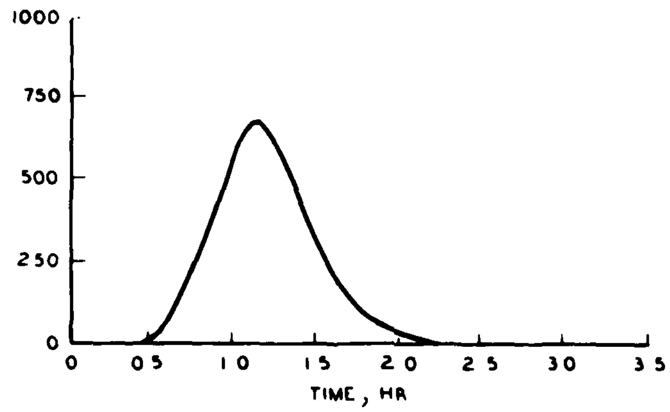
Figure 43. Surface flow, grid sequence 1331, time increment 0.10 hour



a. Direct rainfall component

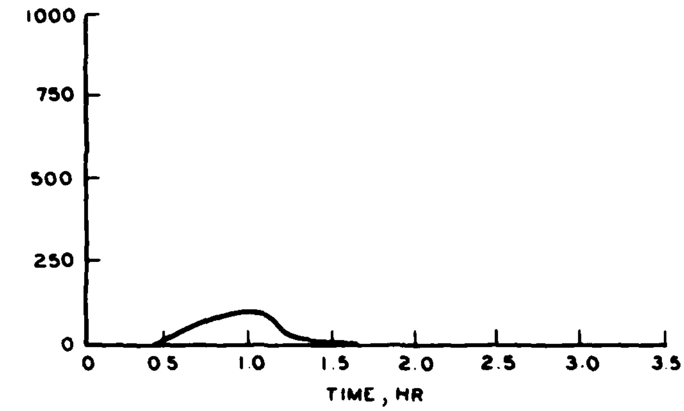


b. Grid-to-grid component

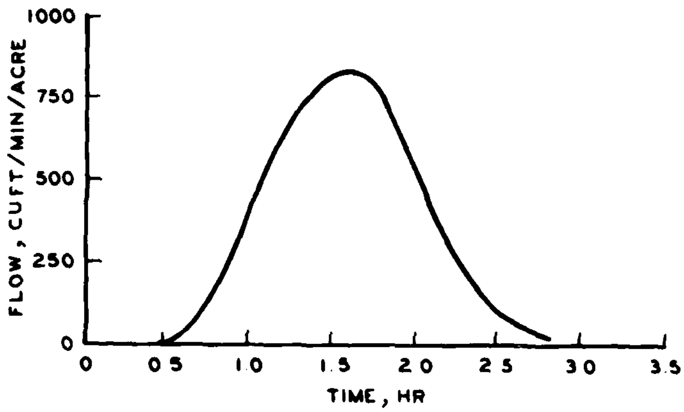


c. Total flow

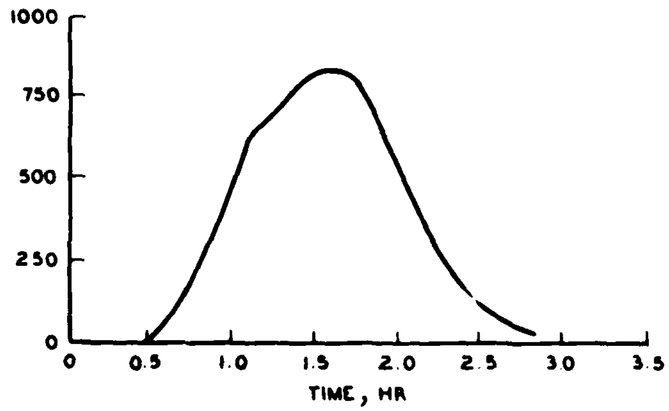
Figure 44. Surface flow, grid sequence 1342, time increment 0.10 hour



a. Direct rainfall component

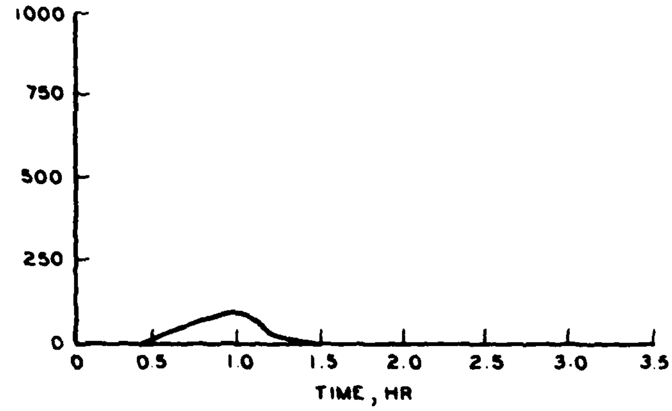


b. Grid-to-grid component

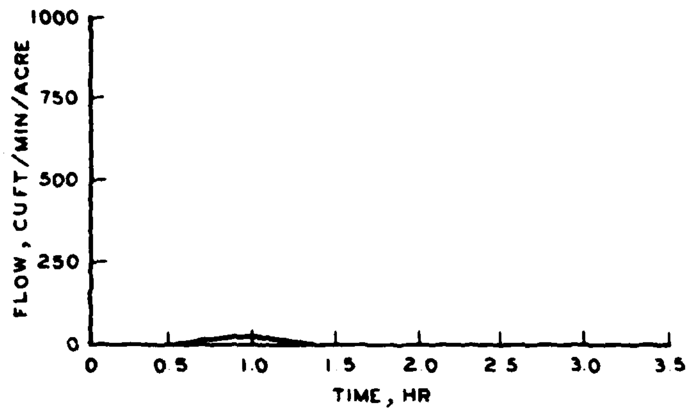


c. Total flow

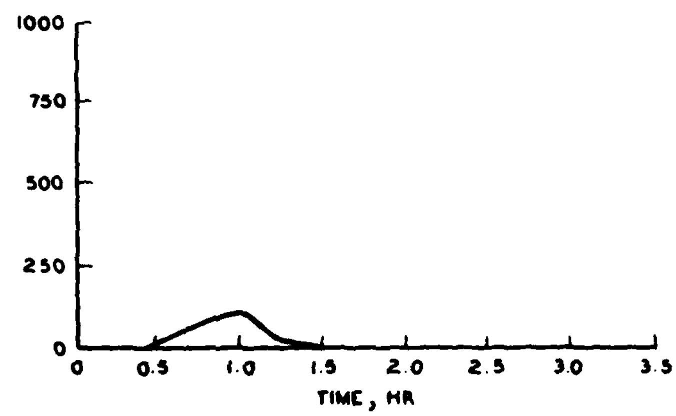
Figure 45. Surface flow, grid sequence 1355, time increment 0.10 hour



a. Direct rainfall component

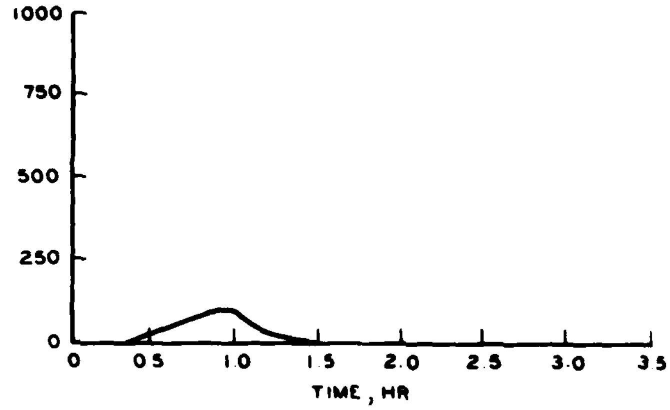


b. Grid-to-grid component

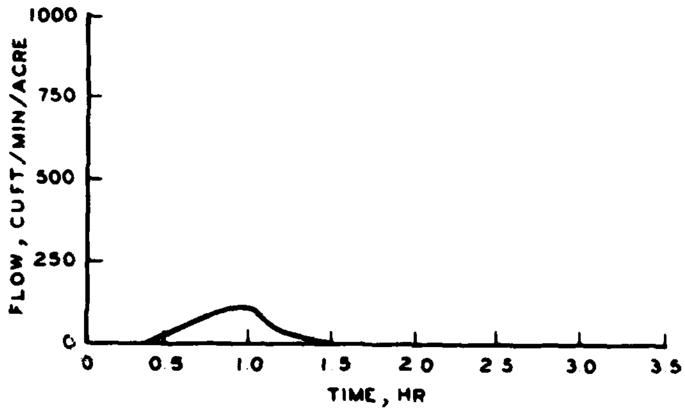


c. Total flow

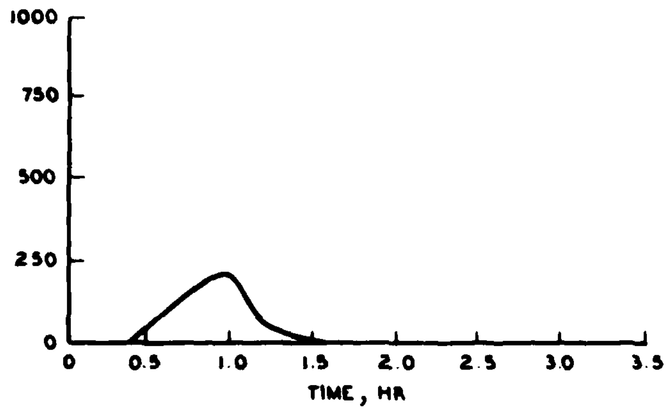
Figure 46. Surface flow, grid sequence 1317, time increment 0.20 hour



a. Direct rainfall component

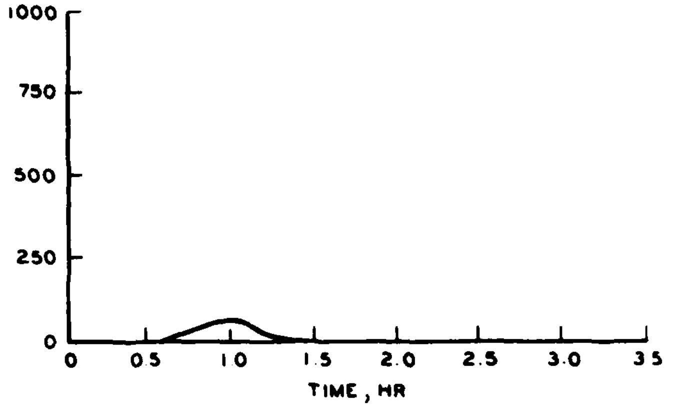


b. Grid-to-grid component

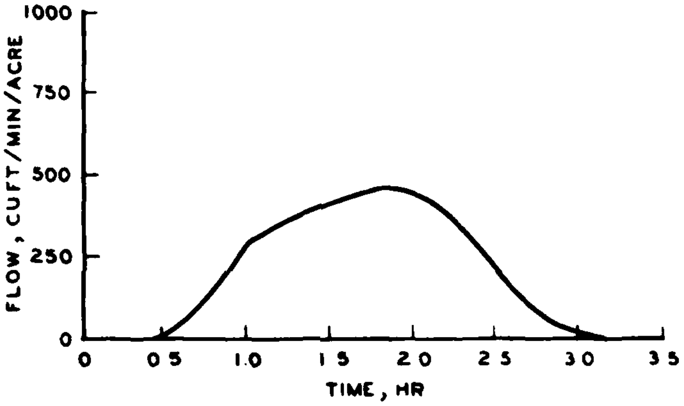


c. Total flow

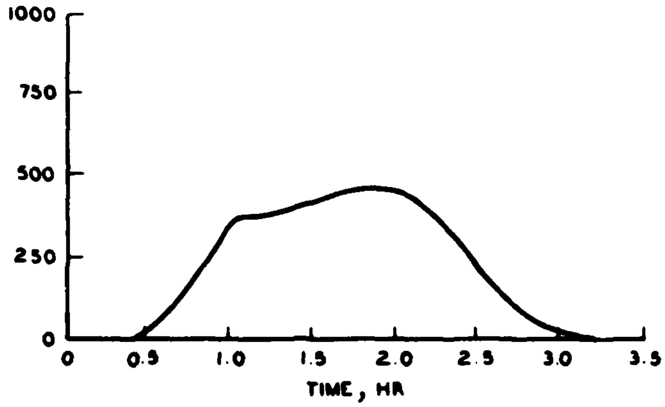
Figure 47. Surface flow, grid sequence 1318, time increment 0.20 hour



a. Direct rainfall component

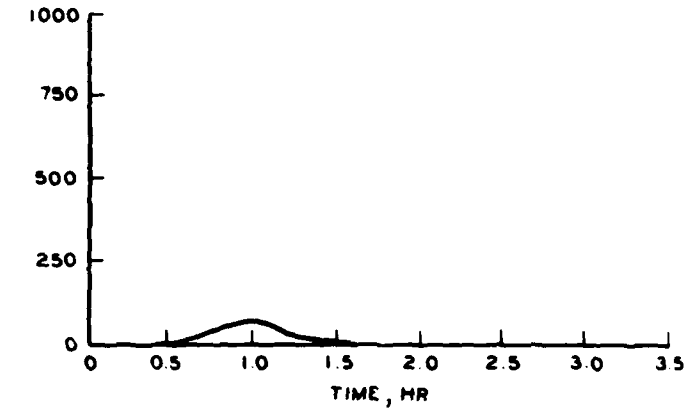


b. Grid-to-grid component

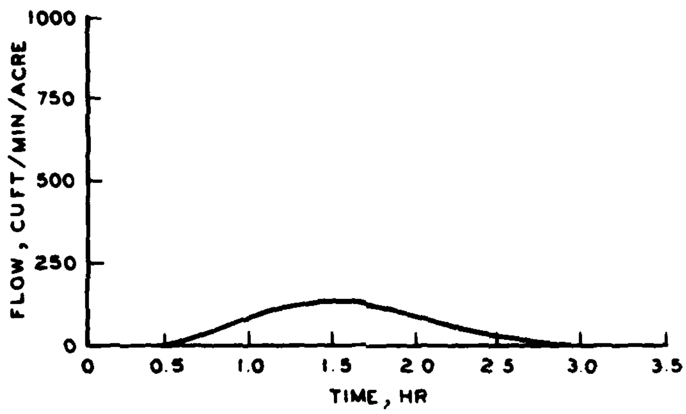


c. Total flow

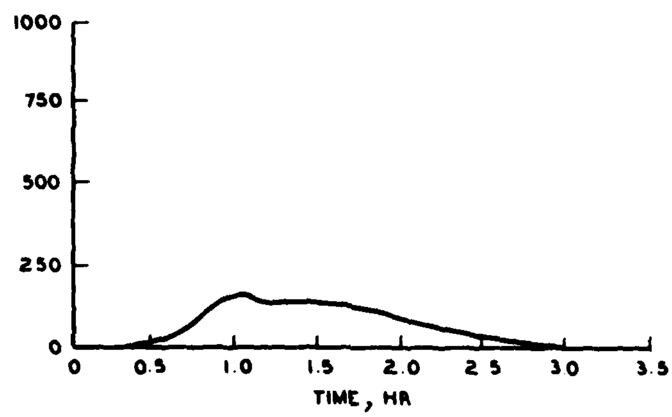
Figure 48. Surface flow, grid sequence 1325, time increment 0.20 hour



a. Direct rainfall component

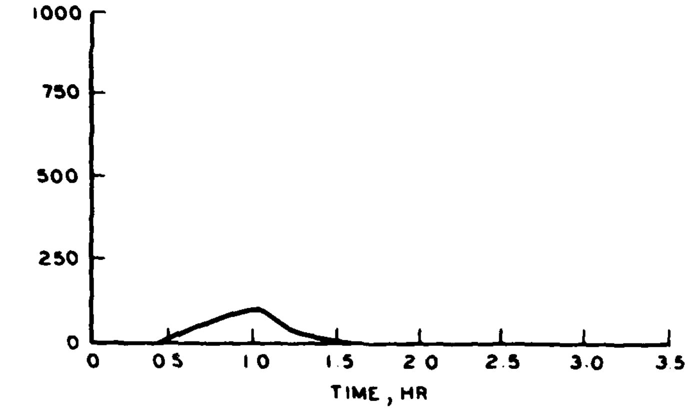


b. Grid-to-grid component

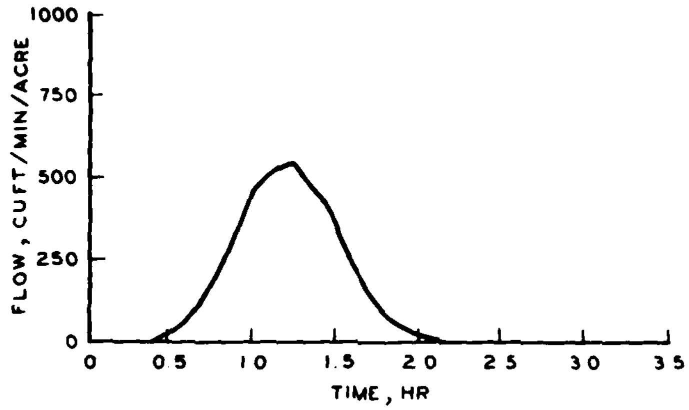


c. Total flow

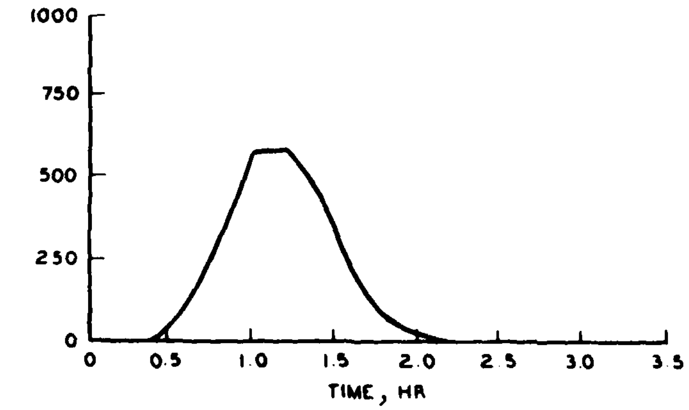
Figure 49. Surface flow, grid sequence 1331, time increment 0.20 hour



a. Direct rainfall component

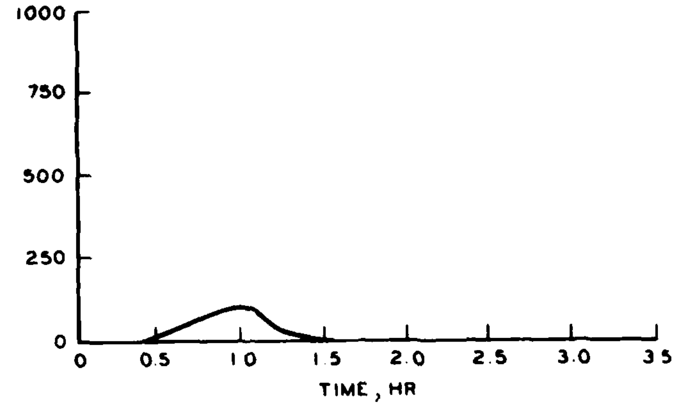


b. Grid-to-grid component

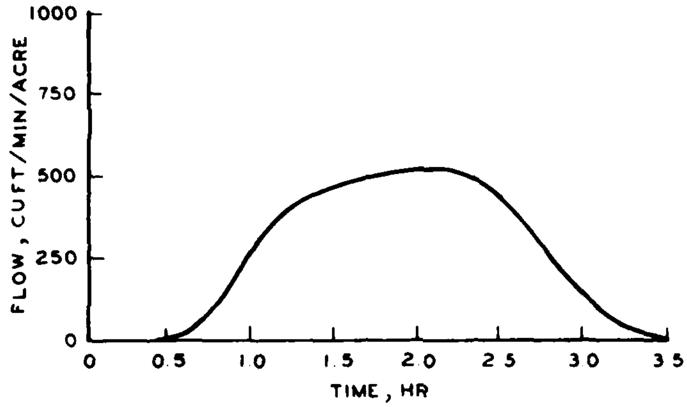


c. Total flow

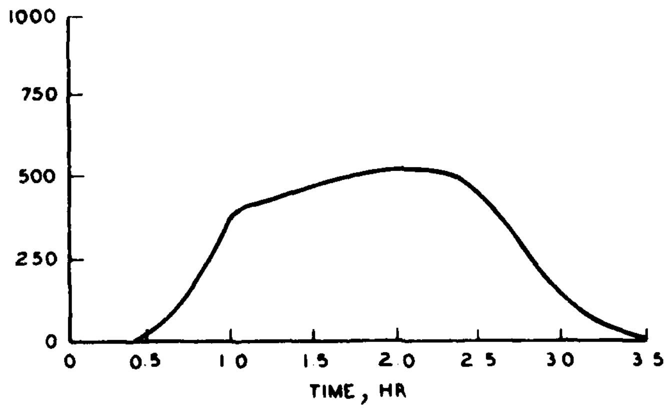
Figure 50. Surface flow, grid sequence 1342, time increment 0.20 hour



a. Direct rainfall component



b. Grid-to-grid component



c. Total flow

Figure 51. Surface flow, grid sequence 1355, time increment 0.20 hour

where

Q_I^N is the total cumulative flow through grid I

$Q_I^E \mid_{CN_I}$ is Equation 21 evaluated for the effective curve number

A_I^E is the effective area of grid I

CN_I^E is the effective curve number of the grid I drainage area

230. The values of A_I^E and CN_I^E are provided by the program DRAIN calculation. There is no "A" term overtly shown in Equation 21 since its units (and the units of the FLOW calculations) are inches/grid/time interval.

231. The total calculated cumulative flow from a grid is the sum of its total cumulative flow components (see Equation 22):

$$Q_I = Q_I^S + Q_I^F \tag{38}$$

where

$$\begin{aligned} Q_I^S &= Q_I^S(t) \Big|_{t = T_M} \\ Q_I^F &= Q_I^F(t) \Big|_{t = T_M} \end{aligned} \tag{39}$$

232. The normalization scale factors N for the components and the total flow are readily seen as follows:

$$\begin{aligned} N_I^S &= \frac{Q_I^S \quad Q_I^N}{\left(Q_I^S + Q_I^F\right)^2} \\ N_I^F &= \frac{Q_I^F \quad Q_I^N}{\left(Q_I^S + Q_I^F\right)^2} \\ N_I &= N_I^S + N_I^F = \frac{Q_I^N}{Q_I^S + Q_I^F} \end{aligned} \tag{40}$$

233. Finally, the normalized flow components and total flow results are calculated using Equations 38-40.

$$
\begin{aligned}
Q_I^{SN}(t) &= N_I^S \, Q_I^S(t) \\
Q_I^{FN}(t) &= N_I^F \, Q_I^F(t) \\
Q_I^N(t) &= Q_I^{SN}(t) + Q_I^{FN}(t) = N_I \left[Q_I^S(t) + Q_I^F(t) \right]
\end{aligned}
\tag{41}
$$

234. These normalized functions are displayed in Tables 9-26 and Figures 34-51.

Output Tables and Graphs

235. The FLOW calculation output contains flow results for 2999 grids (with a 100-m grid interval) for the study watershed. The results for the 6 grids listed in Figure 33 are given in this report as a sample of the calculation output for the eight-nearest-neighbor flow pattern calculation. Since this restricted results display is voluminous and requires the reader's patience for review, the following comments are provided to describe the output sample and to point out some features that were previously described in explanations of the various calculations. This section of the report is intended to provide an orderly, and hopefully informative, walk through the results.

236. Calculation Conditions. Calculations were performed for single- and eight-nearest-neighbor flow allocation patterns for the 0.05-, 0.10-, and 0.20-hour time increments for both 200- and 100-m-grid models of the study watershed. The selected samples in Tables 9-26 and Figures 34-51 are for the 0.05-, 0.10-, and 0.20-hour time intervals, eight-nearest-neighbor flow pattern, 100-m-grid model.

237. Results Layout. The tables and figures are given in the following order.

Tables	Figures	Time Increment, hr
9-14	34-39	0.05
15-20	40-45	0.10
21-26	46-51	0.20

The results for each of the 6 selected grids are provided in the order shown in Figure 33: first for the 0.05-hour time increment, then for the 0.10-hour increment, etc. Studying the results is facilitated if the reader copies them or cuts them out of the report so they can be overlaid on each other or otherwise rearranged for comparison.

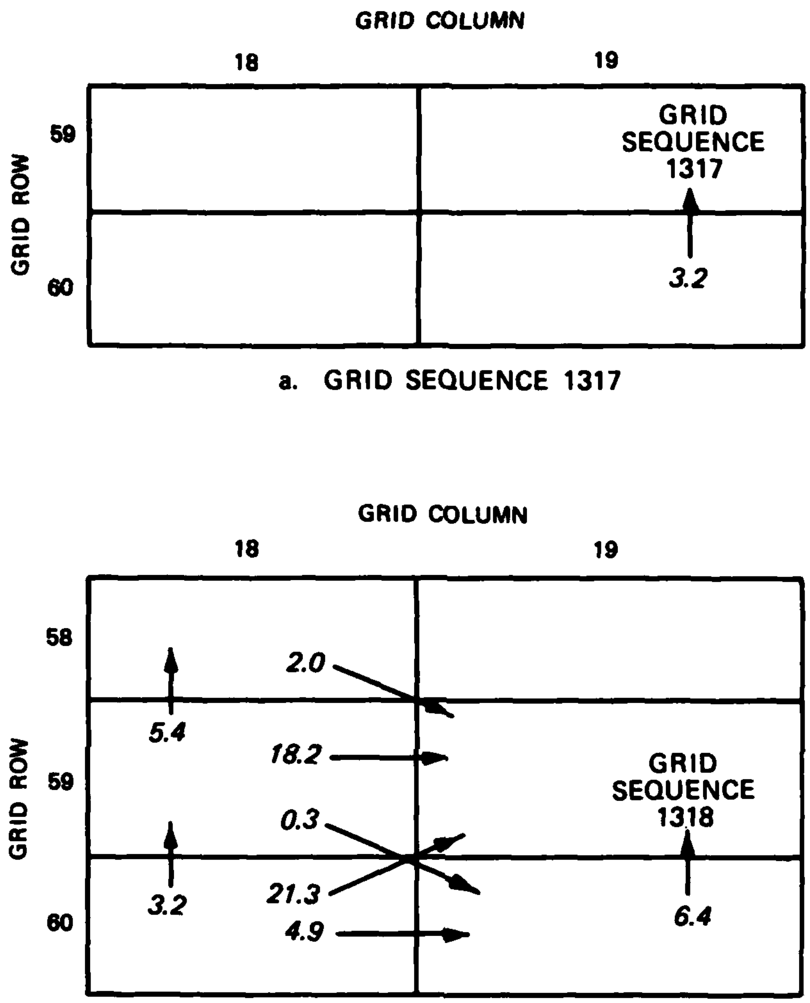
238. Table Contents. Each table contains the normalized inches/grid/time interval and the cubic feet/minute/acre results. Both the cumulative amounts and the amounts per time interval (called the incremental in the tables) are shown for the inches/grid/time interval results, but only the amounts per time interval are shown for the cubic feet/minute/acre results. The direct rainfall and grid-to-grid components and the total flow are shown in the tables under the headings "Rain," "Move," and "Total," respectively.

239. Graph Contents. The figures contain the cubic feet/minute/acre results in a graphic form.

240. Direct Rainfall Component. All direct rainfall component flows are similar in appearance since the same rainfall intensity function was used over the total watershed and the grid curve numbers are similar for the selected grids and for the study watershed (see Figure 33 for the selected grid weighted curve numbers). Although Figures 28 and 32 are for a 200-m-grid model, they indicate the small variation in curve numbers over the watershed.

241. Grid-to-Grid Component. The grid-to-grid component flows vary considerably both in amplitude and shape due to the drainage network differences; these differences between grids involve primarily the flow patterns and lags.

242. Small Drainage Area. Grid sequence 1317 has a small effective drainage area of 1.131 grids (see Figure 33). Table 9 and Figure 34 show that the direct rainfall runoff component (i.e., the component generated by runoff moving from neighboring grids and flow left behind from the direct rainfall runoff that does not flow off the grid during the time interval) is much larger than the grid-to-grid flow component. Figure 52a illustrates the flow allocation network for the 0.05-hour time increment for grid sequence 1317; note that the number



a. GRID SEQUENCE 1317

b. GRID SEQUENCE 1318

Figure 52. Flow networks for small drainage area grids

at the tail of the arrow shows the percent of the flow in temporary storage that will flow from that grid in the direction of the arrow during the flow time interval (i.e., 3.2 percent of the flow in temporary storage on grid (19, 60) flows onto grid (19, 59) in a time interval of 0.05 hour.

243. Grid sequence 1318 also has a small effective drainage area (2.270 grids, see Figure 34), but it is sufficient to produce a grid-to-grid flow comparable to the direct rainfall component (see the

cumulative flow values and peak amplitudes in Table 10 and Figure 35). The flow allocation network for the 0.05-hour time increment is shown in Figure 52b; for example, 0.3 percent of the flow in temporary storage, etc., on grid (18, 59) flows onto grid (19, 60), which then contributes 6.4 percent of its flow to grid (19, 59).

244. Large Drainage Area. If the effective grid drainage area is large, the flow allocation routing with the flow lags determines the shape, amplitude, and peak occurrence time for the grid. Grid sequence 1325 (Table 11 and Figure 36) shows flow curve shapes that are close to the unit hydrograph form. In comparison, the flow curves for grid sequence 1342 (Table 13 and Figure 38) have a similar but more peaked form since the flow network is more compact; i.e., it has fewer grids with a larger flow allocation from each grid, with more direct paths. The shape of the flow curves for grid sequence 1331 (Table 12 and Figure 37) demonstrates what happens when the flow network involves small flow volumes moving over circuitous paths. This grid gathers partial flows from over 35 surrounding grids covering a low topographic relief area. Flow networks for the grids with large drainage areas are traceable in the STRTFLOW output report, but they are too complex for presentation in this report.

245. Rainfall-Flow Lag. The rainfall intensity function (Figure 21) peaks at 0.5 hour and remains constant until 1.0 hour. This shape provides an opportunity to inspect both the lag-to-surface-flow peak time and the shape of the direct rainfall flow component influenced by the (a) initial rainfall abstraction and (b) change in infiltration rate with cumulative rainfall. The direct rainfall component graph for any grid sequence shows the initial abstraction effect on the runoff curve shape. For example, any table shows that practically no flow starts before $t = 0.5$ hour. The direct rainfall component peak occurs at approximately 1.0 hour because of the infiltration rate change; the runoff changes from almost zero to its maximum value at $t = 1.0$ hour.

246. Flow Components' Peaks. The direct rainfall flow component always peaks before the grid-to-grid flow component. Arranging the selected grids in order of increasing drainage area, the reader can see

that the grid-to-grid flow peak's shift to longer time values is directly correlated with the effective drainage area.

247. Equivalent Results for 0.05- and 0.10-hour Increments. An inspection of the tabular data for the 0.05- and 0.10-hour time increment flow calculations shows that the results are practically identical in amplitude, peak time of occurrence, and shape. The only advantage of data with a 0.05 rather than a 0.10 time increment is a better definition of the curves' shape--more an aesthetic preference than an engineering requirement. The implication is that a time increment can be selected by using STRTFLOW in the one-nearest-neighbor flow allocation mode to provide the largest practical calculation time increment for all storm calculations for a given watershed. It is necessary to operate STRTFLOW for different values of Δt, first to bracket and then to iterate in, to select this largest practical value. As previously described in paragraphs 157-159, a visual inspection of the STRTFLOW output report provides a clear indication as to whether the selected Δt is excessive.

248. Excessive Δt. The $\Delta t = 0.20$ calculation results provide data on the effects using an excessive Δt value for the flow calculation. Figure 25 contains the first section of the output report from STRTFLOW that is associated with the flow calculation results shown in Tables 21-26 and Figures 46-51. Note that some, but not all, of the flow allocations are saturated; in fact, an inspection of the total STRTFLOW output report (not provided in this report) shows that the fraction of grids for which $\Delta t = 0.20$ is excessive is far less than indicated in Figure 25. Therefore, the flow results for many grids are unaffected; i.e., see the results for grid sequence 1317 (Table 24, Figure 46).

249. When Δt is too large for a grid so that the calculation assumption of flow to the first-nearest-neighbor grid is violated, the program FLOW retains the correct flow allocation network. However, the program does not permit the flow from a grid to move beyond the first-nearest-neighbor level, so the flow is retarded. The violence this does to the calculation results is apparent in the selected grid examples, and particularly visible in the results for grid sequences 1325 (Table 23, Figure 48) and 1355 (Table 26, Figure 51).

PART V: CONCLUSION

Summary

250. A system was successfully developed for calculating the microgeometric surface flow due to rainfall runoff across the landscape. The system provides all required data preparation, processing, and calculational procedures. The system input consists of data normally available for present hydrology studies and calculational results that show the time history of the surface flow at any selected position on the landscape. The system does not require highly developed technical capabilities of the user, nor does it require special scientific computer capabilities.

251. In the author's opinion, the developed system provides a heretofore unavailable technical capability that has many potential uses for both military and civil applications. One possible basic research application is the use of the system with calibrated watersheds to improve the mathematical approach for calculating rainfall runoff which is used extensively by the Corps and other Federal agencies. This approach almost exclusively involves a macrogeometric approach in which geographic areas are on the order of 1 to 10 square miles or even larger. Calibration of the results is routine and must always be performed, even if improvements are made; however, present calibration work includes not just flow normalization, but also the intelligent varying of parameters in the hydrology and hydraulic portions of the total procedure. In addition, normal calibration steps are sometimes unsuccessful, and the study watershed must be modeled separately for low- and high-intensity storms. The system developed herein permits the researcher to evaluate in detail the basic hydrology, separate from the hydraulics.

252. A similar use with regard to erosion studies is also possible. The surface flow was separated into the direct rainfall and the grid-to-grid flow components specifically for this purpose.

Recommendations

253. It is possible to extend the applicability of the developed system. The following four recommendations address important topics that would provide additional information and capability with a high potential return on investment.

Channel Location

254. The program STRTFLOW contains an algorithm for pit removal described in paragraphs 126-134. If it is operated without designating the channel network, the pit removal algorithm locates the channels in the first few passes. This algorithm could be adapted, principally by removing the correction portion, to locate most-probable channel network locations. This is of interest in studies where there is a construction modification on the landscape. Channel network location is also significant for civil and military intelligence applications in arid regions, whose surfaces display much low-relief topography with little vegetation cover to indicate channel locations on aerial photography, whose topographic maps provide little detailed data.

Evaluation of Excessive Time Increments

255. The relationship between the distortion of the flow function for a grid and the time increment of the flow calculation for the grid's drainage area is unclear. A study should be performed to determine this relationship, where simple measures of distortion such as flow function maximum amplitude and time of occurrence of maximum amplitude could be measured for different Δt flow calculation increments. The result of such a study would provide a rule that could be used by STRTFLOW to automatically choose, with an override option, the Δt required to minimize the flow calculation time and cost. The override option would be used when a greater definition of the flow functions is desired.

Time Varying Flow Allocation

256. It is possible to modify the flow calculation procedure to include time-varying infiltration and lag conditions. A straightforward approach would involve introducing a correction function for the curve number value of a grid so that CN_I would become $CN_I\ [t, Q_I(t)]$.

The function, preferably analytical rather than tabular, would calculate the grid's curve number correction as a function of accumulated rainfall and total flow across the grid. The correction factor could be applied at each Δt interval, and the corrected curve number used to recalculate the flow allocation percentages and the rainfall runoff for that Δt. The inclusion of this capability would have a negligible effect on the operation cost of FLOW and no effect (and require no changes in) any other computer programs in the system.

Irregular Grid Network

257. There is an enormous advantage to be gained in the use of a regular grid model of the terrain surface versus an irregular grid. It is possible, however, to modify the developed system to use an irregular grid model. The manual labor intensive approach would primarily involve discarding programs STRTFLOW and DRAIN and preparing these program's output files manually. After laying out the grid network, the flow allocation network and the effective drainage areas and curve numbers would have to be manually calculated. This would be a formidable task unless the number of irregular grids was very small. In addition, each grid would have to be assigned a flow length for use by FLOW.

258. An approach using a more automated procedure would involve the development of software for grid area calculations, but the flow allocation network and flow lengths determinations would probably remain a manual task. The preference for an irregular rather than a regular terrain grid model indicates that the user wants control of the flow allocation network determination due to special circumstances on the terrain and therefore finds an automatic flow allocation network layout unacceptable.

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Table 1

Land Cover Classes and Runoff Curve Number Determination

Land Cover		Hydrologic Soil Group			
Use	Treatment	1	2	3	4
Fallow	Row	70	79	86	89
Cropland	Row	70	80	86	90
	Contoured	67	77	83	87
	Contoured and terraced	64	72	79	81
	Hay and pasture rotation	55	68	78	83
Woodland	NA	42	66	77	81
Grassland	Hay	36	58	71	78
	Pasture	39	61	74	84
Permanent grassland	Idle	56	69	79	84
Compacted and covered	Farmstead	68	74	82	86
	Urban	72	78	84	87
	Dirt road	72	82	87	89
	Gravel road	73	83	88	90
	Paved road	74	84	90	92
	Railway	73	83	88	90
	Stream and pond	100	100	100	100

Table 2

Digitizing Format for Factor Maps

Using a Digitizer With a Keyboard

Entry*	Name	Description
1**	NDATA	A code used to identify the type of data being digitized
	IDBASE	Code number identifying the base map for which the factor map is an overlay
2**	NCODE NCODE	Code inserted before map corner data; NCODE = -9
3	NXUL NYUL	Digitizer coordinates of the upper left map corner
4	NXUR NYUR	Digitizer coordinates of the upper right map corner
5	NXLL NYLL	Digitizer coordinates of the lower left map corner
6	NXLR NYLR	Digitizer coordinates of the lower right map corner
7**	MXUL MYUL	UTM or state planar coordinates of the upper left map corner
8**	MXLR MYLR	UTM or state planar coordinates of the lower right map corner
9**	NCODE NVAL	Code number inserted before start of digitizer coordinates for patch boundary NCODE = -5555: insert this patch data into the array only where there is no previously digitized data NCODE = -6666: insert this patch data into the array and overlay any data found at its location NVAL = value of the patch
10	NX NY	Digitizer coordinates of a point on the patch boundary (Record 10 is repeated for all points on the patch boundary.)
		(Records 9-10 are repeated for every patch.)
11**	ICODE ICODE	Code number signifying the end of the data file; ICODE = -9999
		(An end-of-file is placed after this record.)

* All entries are in 2I6 format.

** Use the keyboard to record these data.

Table 3

Digitizing Format for Elevation Data on Contour Maps Using a Digitizer With a Keyboard

Entry*	Name	Description
1**	NDATA IDBASE	Identifies the type of data; NDATA = 4 Code number identifying the base map from which the data are to be digitized
2**	NCODE	Code inserted before map corner data; NCODE = -9
3	NXUL NYUL	Digitizer coordinates of the upper left map corner
4	NXUR NYUR	Digitizer coordinates of the upper right map corner
5	NXLL NYLL	Digitizer coordinates of the lower left map corner
6	NXLR NYLR	Digitizer coordinates of the lower right map corner
7**	MXUL MYUL	UTM coordinates of the upper left map corner in thousands of metres
8**	MXLR MYLR	UTM coordinates of the lower right map corner in thousands of metres
The following data are digitized from the area-of-interest map overlay.		
9**	NCODE NVAL	Code number before start of digitizer coordinates for area-of-interest patch boundary; NCODE = -5555 NVAL = 0
10	NX NY	Digitizer coordinates of a point on the area-of-interest patch boundary (Record 10 is repeated for all points on the area-of-interest patch boundary.)
(Records 9-10 are repeated for every patch.)		
16**	NCODE NVAL	Code before a string of X,Y coordinates of a contour line, or the X,Y coordinates of a spot elevation; NCODE = -7777 NVAL = elevation of the contour line or spot elevation

(Continued)

* All entries are 216 format.

** Use the keyboard to record these data.

Table 3 (Concluded)

Entry	Name	Description
		The following data are digitized from the contour map.
17	NX NY	Digitizer coordinates of a point on the contour line or of a spot elevation
		(Record 17 appears once for a spot elevation, but appears as many times as necessary to define a contour line location. Records 10-17 are repeated for all contour lines.)
		The following data are digitized from the photo and contour maps
18**	NCODE NVAL	Code before string of X,Y coordinates defining a stream location; NCODE = -4444 NVAL = elevation of the stream at the start of the string of X,Y coordinates following this record
19	NX NY	Digitizer coordinates of the starting point on the stream
20	NX NY	Digitizer coordinates of a point on the stream location
		(Record 20 is repeated as many times as necessary; the distance between points is the distance to the nearer neighboring contour line.)
21	NX NY	Digitizer coordinates of the last point on the stream before encountering a contour line crossing the stream
22**	NCODE NVAL	Code before X,Y coordinates of the intersection of the stream with a contour line; NCODE = -4444 NVAL = contour line elevation
23	NX NY	Digitizer coordinates of the intersection of the stream with a contour line
		(Records 20-23 are repeated as many times as necessary to account for all contour lines intersecting the stream.)
24**	NCODE NVAL	Code to denote the end of the string of data defining the stream location; NCODE = -4444 NVAL = estimated stream elevation at the last NX, NY location digitized
		(Records 18-24 are repeated for the main stream and for each tributary.)
11**	ICODE	Code number signifying the end of the data file; ICODE = -9999 (An end-of-file is placed after this record.)

** Use the keyboard to record these data.

Table 4

Soil Types

Map Symbol	Mapping Unit
LcC3	Lexington silty clay loam, 5 to 8 percent slopes, severely eroded
LcD3	Lexington silty clay loam, 8 to 12 percent slopes, severely eroded
LeD	Lexington-Ruston complex, 8 to 12 percent slopes
LeD3	Lexington-Ruston complex, 8 to 12 percent slopes, severely eroded
LeF	Lexington-Ruston complex, 12 to 30 percent slopes
LeF3	Lexington-Ruston complex, 12 to 30 percent slopes, severely eroded
LfD	Lexington-Ruston-Gullied land complex, 8 to 12 percent slopes
LfF	Lexington-Ruston-Gullied land complex, 12 to 30 percent slopes
LgD	Loring-Gullied land complex, 5 to 12 percent slopes
LgE	Loring-Gullied land complex, 12 to 20 percent slopes
LoA	Loring silt loam, 0 to 2 percent slopes
LoB	Loring silt loam, 2 to 5 percent slopes
LoB3	Loring silt loam, 2 to 5 percent slopes, severely eroded
LoC	Loring silt loam, 5 to 8 percent slopes
LoC3	Loring silt loam, 5 to 8 percent slopes, severely eroded
LoD	Loring silt loam, 8 to 12 percent slopes
LoD3	Loring silt loam, 8 to 12 percent slopes, severely eroded
LoE	Loring silt loam, 12 to 20 percent slopes
LoE3	Loring silt loam, 12 to 20 percent slopes, severely eroded
MeA	Memphis silt loam, 0 to 2 percent slopes
MeB	Memphis silt loam, 2 to 5 percent slopes
MeC	Memphis silt loam, 5 to 8 percent slopes
MeD	Memphis silt loam, 8 to 12 percent slopes
MfB3	Memphis silty clay loam, 2 to 5 percent slopes, severely eroded
MfC3	Memphis silty clay loam, 5 to 8 percent slopes, severely eroded
MfD3	Memphis silty clay loam, 8 to 12 percent slopes, severely eroded
MgD	Memphis-Gullied land complex, 5 to 12 percent slopes
MgE	Memphis-Gullied land complex, 12 to 20 percent slopes
RcF3	Ruston sandy clay loam, 12 to 30 percent slopes, severely eroded
RdF	Ruston sandy loam, 12 to 30 percent slopes
ReF	Ruston-Eustis complex, 12 to 30 percent slopes
Sa	Sandy alluvial land
Sw	Swamp
Vb	Vicksburg fine sandy loam
Vc	Vicksburg fine sandy loam, local alluvium
Vk	Vicksburg silt loam
Vu	Vicksburg silt loam, local alluvium
Wa	Waverly fine sand loam
Wv	Waverly silt loam
CaA	Calloway silt loam, 0 to 2 percent slopes
CaB	Calloway silt loam, 2 to 5 percent slopes
CaB2	Calloway silt loam, 2 to 5 percent slopes, eroded
CbA	Calloway silt loam, terrace, 0 to 2 percent slopes
CbB	Calloway silt loam, terrace, 2 to 5 percent slopes
CbB2	Calloway silt loam, terrace, 2 to 5 percent slopes, eroded
Cf	Collins fine sand loam
Cm	Collins fine sand loam, local alluvium
Co	Collins silt loam
Cu	Collins silt loam, local alluvium
Fa	Falaya fine sand loam
Ff	Falaya fine sandy loam, local alluvium
Fm	Falaya silt loam

(Continued)

Table 4 (Concluded)

Map Symbol	Mapping Unit
Fu	Falaya silt loam, local alluvium
GaA	Grenada silt loam, 0 to 2 percent slopes
GaB	Grenada silt loam, 2 to 5 percent slopes
GaB2	Grenada silt loam, 2 to 5 percent slopes, eroded
GaB3	Grenada silt loam, 2 to 5 percent slopes, severely eroded
GaC	Grenada silt loam, 5 to 8 percent slopes
GaC2	Grenada silt loam, 5 to 8 percent slopes, eroded
GaC3	Grenada silt loam, 5 to 8 percent slopes, severely eroded
GaD	Grenada silt loam, 8 to 12 percent slopes
GaD3	Grenada silt loam, 8 to 12 percent slopes, severely eroded
GbA	Grenada silt loam, terrace, 0 to 2 percent slopes
GbB	Grenada silt loam, terrace, 2 to 5 percent slopes
GbB2	Grenada silt loam, terrace, 2 to 5 percent slopes, eroded
GbB3	Grenada silt loam, terrace, 2 to 5 percent slopes, severely eroded
GbC2	Grenada silt loam, terrace, 5 to 8 percent slopes, eroded
GbC3	Grenada silt loam, terrace, 5 to 8 percent slopes, severely eroded
GgC	Grenada-Gullied land complex, 5 to 8 percent slopes
GgD	Grenada-Gullied land complex, 8 to 12 percent slopes
Gn	Gullied land, sandy
Gs	Gullied land, silty
He	Henry silt loam
Ho	Henry silt loam, overwash
Ht	Henry silt loam, terrace
LbB	Lexington silt loam, 2 to 5 percent slopes
LbC	Lexington silt loam, 5 to 8 percent slopes
LbD	Lexington silt loam, 8 to 12 percent slopes
LcB3	Lexington silty clay loam, 2 to 5 percent slopes, severely eroded

Table 5

Soil Types and Hydrologic Groups

Hydrologic Group	Soil Type
C	Arkabutla
B	Cahaba and Lexington
B	Cahaba-Providence
C	Calloway
B	Cascilla
C	Collins
C	Falaya
C	Grenada
A	Gullied land, Cahaba complex
C	Gullied land, Loring complex
D	Henry
D	Lexington
C	Loring
C	Luverne
B	Memphis
B	Ochlockonee
C	Providence
B	Ruston
A	Sandy alluvial
D	Swamp
B	Vicksburg
B	Waverly

Table 6

Land Use Classes

Land Use Code	Land Use
1	Cropland, row crops
2	Cropland, close growing crops
3	Recreation area
4	Cropland, double cropped
5	Horticultural areas
6	Grassland, good cover
7	Grassland, poor cover
8	Idle land
9	Deciduous forest land
10	Coniferous forest land
11	Mixed hardwoods-pine forest land
12	Brushland
13	Other related agricultural land
14	Feeding operations
15	Rural, nonfarm land
16	Urban, residential
17	Urban, commercial and services
18	Urban, industrial
19	Urban, open land
20	Water area
21	Natural lakes and swamps
22	Other land uses

Table 7

Curve Numbers for Average Antecedent Moisture Conditions

Land Use		Hydrologic Soil Group			
Code	Name	1	2	3	4
1	Row crops	64	72	79	81
2	Close-growing crops	70	79	84	88
3	Recreation area	72	81	88	91
4	Double-cropped cropland	65	75	82	86
5	Horticultural area	67	77	83	87
6	Good cover grassland	62	71	78	81
7	Poor cover grassland	70	80	86	90
8	Idle land	55	68	78	83
9	Deciduous forest	68	79	86	99
10	Coniferous forest	71	79	86	89
11	Hardwoods/pine mixed forest	42	66	77	81
12	Brushland	42	66	77	81
13	Other related agricultural land	42	66	77	81
14	Feeding operations	42	66	77	81
15	Nonfarm rural land	72	82	87	89
16	Urban residential	49	69	79	84
17	Urban commercial services	39	61	74	80
18	Urban industrial	72	79	84	87
19	Urban open land	74	84	90	92
20	Ponds, rivers, lakes, swamps	100	100	100	100

Table 8

Drainage Area Frequency Distributions

Drainage Area ha	Number of Occurrences, grids: 100-m-grid Nearest-Neighbor Flow 1	100-m-grid Nearest-Neighbor Flow 8	200-m-grid Nearest-Neighbor Flow 1	200-m-grid Nearest-Neighbor Flow 8
1	1291	639	0	0
2	645	915	0	0
3	368	501	0	0
4	180	307	421	100
5	137	207	0	112
6	87	133	0	115
7	85	89	0	84
8	41	35	187	62
9	32	37	0	58
10	29	30	0	45
11	23	11	0	42
12	13	23	87	31
13	10	12	0	25
14	6	5	0	18
15	12	10	0	11
16	9	6	43	8
17	5	6	0	11
18	8	4	0	4
19	4	2	0	5
20	7	3	21	3
21	2	3	0	4
22	4	1	0	2
23	2	0	0	1
24	4	1	9	3
25	1	1	0	0
26	3	1	0	2
27	1	4	0	1
28	1	1	3	0
29	2	0	0	0
30	2	1	0	1
31	1	1	0	0
32	1	1	4	2
33	0	0	0	0
34	1	0	0	0
35	0	0	0	1
36	1	0	2	0
37	0	0	0	0
38	0	1	0	1
39	1	1	0	0
40	0	0	2	0
41	0	0	0	0
42	0	2	0	1
43	1	0	0	0
44	0	0	2	0
45	0	1	0	1
46	0	0	0	0
47	0	0	0	0
48	0	0	0	0
49	0	0	0	0
>49	8	3	3	1

Table 9

Surface Flow Time History, Grid Sequence 1317, for a 0.05-Hour Time Increment

	SURFACE FLOW TIME HISTORY								
	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.05	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.15	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.25	0.	0.	C.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.35	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.45	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.01	0.00	0.01	0.01	0.00	0.01	8	0	8
0.55	0.03	0.00	0.03	0.02	0.00	0.02	26	1	27
0.60	0.06	0.00	C.07	0.03	0.00	0.04	40	2	42
0.65	0.11	0.01	0.11	0.04	0.00	0.05	52	4	56
0.70	0.16	0.01	0.17	0.05	0.00	0.06	62	5	67
0.75	0.22	0.02	0.23	0.06	0.01	0.06	70	6	76
0.80	0.28	0.02	0.30	0.06	0.01	0.07	77	7	84
0.85	0.35	0.03	0.38	0.07	0.01	0.08	84	8	92
0.90	0.42	0.04	0.46	0.07	0.01	0.08	89	9	98
0.95	0.50	0.05	0.55	0.08	0.01	0.09	94	10	104
1.00	0.58	0.06	C.64	0.08	0.01	0.09	98	11	109
1.05	0.66	0.07	0.73	0.08	0.01	0.09	99	11	110
1.10	0.73	0.08	C.81	0.06	0.01	0.07	78	11	89
1.15	0.77	0.08	0.85	0.04	0.01	0.05	47	9	56
1.20	0.79	0.09	0.88	0.02	0.01	0.03	26	7	33
1.25	0.81	0.10	0.90	0.01	0.00	0.02	17	5	22
1.30	0.82	0.10	0.92	0.01	0.00	0.01	13	4	17
1.35	0.83	0.10	C.93	0.01	0.00	0.01	10	3	13
1.40	0.83	0.10	0.94	0.01	0.00	0.01	8	2	10
1.45	0.84	0.11	0.94	0.00	0.00	0.01	5	2	7
1.50	0.84	0.11	0.95	0.00	0.00	0.00	4	1	5
1.55	0.84	0.11	0.95	0.00	0.00	0.00	3	1	4
1.60	0.85	0.11	0.95	0.00	0.00	0.00	2	0	2
1.65	0.85	0.11	0.96	0.00	0.00	0.00	1	0	1
1.70	0.85	0.11	0.96	0.00	0.00	0.00	1	0	1
1.75	0.85	0.11	C.96	0.00	0.00	0.00	0	0	0
1.80	0.85	0.11	0.96	0.00	0.00	0.00	0	0	0
1.85	0.85	0.11	0.96	0.00	0.00	0.00	0	0	0
1.90	0.85	0.11	0.96	0.00	0.00	0.00	0	0	0
1.95	0.85	0.11	0.96	0.00	0.00	0.00	0	0	0
2.00	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.05	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.10	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.15	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.20	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.25	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.30	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.35	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.40	0.85	0.11	C.96	0.	0.	0.	0	0	0
2.45	0.85	0.11	C.96	0.	0.	0.	0	0	0
2.50	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.55	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.60	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.65	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.70	0.85	0.11	0.96	0.	0.	0.	0	0	0

Table 10

Surface Flow Time History, Grid Sequence 1318, for a 0.05-Hour Time Increment

	SURFACE FLOW TIME HISTORY								
	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.05	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.15	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.25	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.35	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.45	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.01	0.00	0.01	0.01	0.00	0.01	8	3	11
0.55	0.03	0.01	0.04	0.02	0.01	0.03	26	12	38
0.60	0.06	0.03	0.10	0.03	0.02	0.05	40	24	64
0.65	0.11	0.06	0.17	0.04	0.03	0.07	52	37	89
0.70	0.16	0.11	0.26	0.05	0.04	0.09	62	49	111
0.75	0.22	0.16	0.37	0.06	0.05	0.11	70	60	130
0.80	0.28	0.22	0.50	0.06	0.06	0.12	77	71	148
0.85	0.35	0.28	0.63	0.07	0.07	0.14	84	80	164
0.90	0.42	0.36	0.78	0.07	0.07	0.15	89	89	178
0.95	0.50	0.43	0.94	0.08	0.08	0.16	94	96	190
1.00	0.58	0.52	1.10	0.08	0.09	0.17	98	102	200
1.05	0.66	0.61	1.27	0.08	0.09	0.17	99	107	206
1.10	0.73	0.69	1.42	0.06	0.08	0.15	78	101	179
1.15	0.77	0.76	1.53	0.04	0.07	0.11	47	85	132
1.20	0.79	0.82	1.61	0.02	0.05	0.08	26	66	92
1.25	0.81	0.86	1.67	0.01	0.04	0.06	17	50	67
1.30	0.82	0.89	1.71	0.01	0.03	0.04	13	38	51
1.35	0.83	0.92	1.74	0.01	0.02	0.03	10	29	39
1.40	0.83	0.93	1.77	0.01	0.02	0.03	8	22	30
1.45	0.84	0.95	1.79	0.00	0.01	0.02	5	16	21
1.50	0.84	0.96	1.80	0.00	0.01	0.01	4	12	16
1.55	0.84	0.97	1.81	0.00	0.01	0.01	3	9	12
1.60	0.85	0.97	1.82	0.00	0.01	0.01	2	7	9
1.65	0.85	0.98	1.82	0.00	0.00	0.01	1	5	6
1.70	0.85	0.98	1.83	0.00	0.00	0.00	1	3	4
1.75	0.85	0.98	1.83	0.00	0.00	0.00	0	2	2
1.80	0.85	0.98	1.83	0.00	0.00	0.00	0	2	2
1.85	0.85	0.99	1.83	0.00	0.00	0.00	0	1	1
1.90	0.85	0.99	1.84	0.00	0.00	0.00	0	1	1
1.95	0.85	0.99	1.84	0.00	0.00	0.00	0	0	0
2.00	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.05	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.10	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.15	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.20	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.25	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.30	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.35	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.40	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.45	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.50	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.55	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.60	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.65	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.70	0.85	0.99	1.84	0.	0.	0.	0	0	0

Table 11

Surface Flow Time History, Grid Sequence 1325, for a 0.05-Hour Time Increment

	SURFACE FLOW TIME HISTORY								
	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.05	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.15	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.25	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.35	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.45	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.	0.01	0.01	0.	0.01	0.01	0	7	7
0.55	0.00	0.03	0.03	0.00	0.02	0.02	0	27	27
0.60	0.01	0.07	0.08	0.01	0.04	0.05	8	54	62
0.65	0.02	0.15	0.17	0.02	0.07	0.09	19	86	105
0.70	0.05	0.25	0.30	0.02	0.10	0.13	29	125	154
0.75	0.08	0.39	0.47	0.03	0.14	0.17	38	171	209
0.80	0.12	0.58	0.69	0.04	0.19	0.22	46	225	271
0.85	0.16	0.81	0.98	0.04	0.24	0.28	53	286	339
0.90	0.21	1.11	1.32	0.05	0.29	0.34	59	355	414
0.95	0.27	1.46	1.73	0.05	0.36	0.41	64	430	494
1.00	0.32	1.89	2.21	0.06	0.42	0.48	70	511	581
1.05	0.38	2.38	2.76	0.06	0.49	0.55	72	595	667
1.10	0.43	2.92	3.35	0.05	0.55	0.59	58	660	718
1.15	0.46	3.50	3.96	0.03	0.58	0.61	36	701	737
1.20	0.48	4.10	4.58	0.02	0.60	0.62	20	726	746
1.25	0.49	4.72	5.21	0.01	0.62	0.63	13	744	757
1.30	0.50	5.34	5.84	0.01	0.63	0.63	10	756	766
1.35	0.50	5.97	6.48	0.01	0.63	0.63	7	758	765
1.40	0.51	6.59	7.10	0.01	0.62	0.62	6	749	755
1.45	0.51	7.19	7.70	0.00	0.60	0.60	4	726	730
1.50	0.52	7.76	8.28	0.00	0.57	0.57	3	691	694
1.55	0.52	8.30	8.82	0.00	0.53	0.54	2	646	648
1.60	0.52	8.79	9.31	0.00	0.49	0.49	2	594	596
1.65	0.52	9.23	9.75	0.00	0.44	0.44	1	536	537
1.70	0.52	9.63	10.15	0.00	0.39	0.39	0	476	476
1.75	0.52	9.97	10.49	0.00	0.34	0.34	0	416	416
1.80	0.52	10.27	10.79	0.00	0.30	0.30	0	360	360
1.85	0.52	10.52	11.04	0.00	0.25	0.25	0	307	307
1.90	0.52	10.74	11.26	0.00	0.21	0.21	0	259	259
1.95	0.52	10.91	11.44	0.00	0.18	0.18	0	216	216
2.00	0.52	11.06	11.59	0.	0.15	0.15	0	179	179
2.05	0.52	11.18	11.71	0.	0.12	0.12	0	147	147
2.10	0.52	11.28	11.81	0.	0.10	0.10	0	119	119
2.15	0.52	11.36	11.89	0.	0.08	0.08	0	96	96
2.20	0.52	11.43	11.95	0.	0.06	0.06	0	77	77
2.25	0.52	11.48	12.00	0.	0.05	0.05	0	62	62
2.30	0.52	11.52	12.04	0.	0.04	0.04	0	49	49
2.35	0.52	11.55	12.07	0.	0.03	0.03	0	38	38
2.40	0.52	11.58	12.10	0.	0.03	0.03	0	30	30
2.45	0.52	11.60	12.12	0.	0.02	0.02	0	23	23
2.50	0.52	11.61	12.13	0.	0.02	0.02	0	18	18
2.55	0.52	11.62	12.15	0.	0.01	0.01	0	14	14
2.60	0.52	11.63	12.16	0.	0.01	0.01	0	10	10
2.65	0.52	11.64	12.16	0.	0.01	0.01	0	8	8
2.70	0.52	11.64	12.17	0.	0.01	0.01	0	6	6

Table 12

Surface Flow Time History, Grid Sequence 1331, for a 0.05-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.05	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.15	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.25	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.35	0.	0.00	0.00	0.	0.00	0.00	0	0	0
0.40	0.	0.00	0.00	0.	0.00	0.00	0	0	0
0.45	0.	0.00	0.00	0.	0.00	0.00	0	1	1
0.50	0.	0.01	0.01	0.	0.00	0.00	0	4	4
0.55	0.00	0.01	0.01	0.00	0.01	0.01	0	9	9
0.60	0.01	0.03	0.03	0.01	0.01	0.02	8	16	24
0.65	0.02	0.05	0.07	0.02	0.02	0.04	19	26	45
0.70	0.05	0.08	0.13	0.02	0.03	0.06	29	36	65
0.75	0.08	0.12	0.20	0.03	0.04	0.07	38	49	87
0.80	0.12	0.17	0.29	0.04	0.05	0.09	46	63	109
0.85	0.16	0.24	0.40	0.04	0.07	0.11	53	78	131
0.90	0.21	0.32	0.53	0.05	0.08	0.13	59	95	154
0.95	0.27	0.41	0.67	0.05	0.09	0.15	64	112	176
1.00	0.32	0.52	0.84	0.06	0.11	0.17	70	130	200
1.05	0.38	0.64	1.02	0.06	0.12	0.18	72	148	220
1.10	0.43	0.77	1.20	0.05	0.13	0.18	58	160	218
1.15	0.46	0.91	1.37	0.03	0.14	0.17	36	165	201
1.20	0.48	1.05	1.53	0.02	0.14	0.15	20	166	186
1.25	0.49	1.18	1.67	0.01	0.14	0.15	13	166	179
1.30	0.50	1.32	1.82	0.01	0.14	0.15	10	165	175
1.35	0.50	1.45	1.96	0.01	0.13	0.14	7	162	169
1.40	0.51	1.58	2.09	0.01	0.13	0.13	6	157	163
1.45	0.51	1.71	2.22	0.00	0.12	0.13	4	150	154
1.50	0.52	1.83	2.34	0.00	0.12	0.12	3	142	145
1.55	0.52	1.94	2.45	0.00	0.11	0.11	2	133	135
1.60	0.52	2.04	2.56	0.00	0.10	0.10	2	124	126
1.65	0.52	2.13	2.65	0.00	0.10	0.10	1	115	116
1.70	0.52	2.22	2.74	0.00	0.09	0.09	0	106	106
1.75	0.52	2.30	2.82	0.00	0.08	0.08	0	97	97
1.80	0.52	2.38	2.90	0.00	0.07	0.07	0	89	89
1.85	0.52	2.44	2.97	0.00	0.07	0.07	0	81	81
1.90	0.52	2.51	3.03	0.00	0.06	0.06	0	74	74
1.95	0.52	2.56	3.08	0.00	0.06	0.06	0	68	68
2.00	0.52	2.61	3.14	0.	0.05	0.05	0	62	62
2.05	0.52	2.66	3.18	0.	0.05	0.05	0	56	56
2.10	0.52	2.70	3.23	0.	0.04	0.04	0	51	51
2.15	0.52	2.74	3.26	0.	0.04	0.04	0	46	46
2.20	0.52	2.78	3.30	0.	0.04	0.04	0	42	42
2.25	0.52	2.81	3.33	0.	0.03	0.03	0	38	38
2.30	0.52	2.84	3.36	0.	0.03	0.03	0	35	35
2.35	0.52	2.86	3.39	0.	0.03	0.03	0	31	31
2.40	0.52	2.89	3.41	0.	0.02	0.02	0	29	29
2.45	0.52	2.91	3.43	0.	0.02	0.02	0	26	26
2.50	0.52	2.93	3.45	0.	0.02	0.02	0	24	24
2.55	0.52	2.95	3.47	0.	0.02	0.02	0	21	21
2.60	0.52	2.96	3.49	0.	0.02	0.02	0	19	19
2.65	0.52	2.98	3.50	0.	0.01	0.01	0	18	18
2.70	0.52	2.99	3.52	0.	0.01	0.01	0	16	16

Table 13

Surface Flow Time History, Grid Sequence 1342, for a 0.05-Hour Time Increment

SURFACE FLOW TIME HISTORY									
	SURFACE FLOW,IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.05	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.15	0.	0.	C.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.25	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.35	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.45	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.01	0.00	0.01	0.01	0.00	0.01	8	3	11
0.55	0.03	0.01	C.04	0.02	0.01	0.03	26	13	39
0.60	0.06	0.04	0.11	0.03	0.03	0.06	40	35	75
0.65	0.11	0.10	0.20	0.04	0.06	0.10	52	68	120
0.70	0.16	0.19	0.35	0.05	0.09	0.14	62	109	171
0.75	0.22	0.32	0.54	0.06	0.13	0.19	70	158	228
0.80	0.28	0.50	0.78	0.06	0.18	0.24	77	213	290
0.85	0.35	0.72	1.07	0.07	0.23	0.30	84	273	357
0.90	0.42	1.00	1.43	0.07	0.28	0.35	89	336	425
0.95	0.50	1.33	1.84	0.08	0.33	0.41	94	401	495
1.00	0.58	1.72	2.30	0.08	0.39	0.47	98	466	564
1.05	0.66	2.16	2.82	0.08	0.44	0.52	99	529	628
1.10	0.73	2.63	3.36	0.06	0.47	0.54	78	569	647
1.15	0.77	3.10	3.87	0.04	0.48	0.52	47	577	624
1.20	0.79	3.57	4.36	0.02	0.46	0.49	26	560	586
1.25	0.81	4.00	4.81	0.01	0.44	0.45	17	529	546
1.30	0.82	4.41	5.23	0.01	0.40	0.42	13	489	502
1.35	0.83	4.78	5.60	0.01	0.37	0.38	10	443	453
1.40	0.83	5.10	5.94	0.01	0.33	0.33	8	395	403
1.45	0.84	5.39	6.23	0.00	0.29	0.29	5	346	351
1.50	0.84	5.64	6.48	0.00	0.25	0.25	4	299	303
1.55	0.84	5.85	6.69	0.00	0.21	0.21	3	256	259
1.60	0.85	6.03	6.87	0.00	0.18	0.18	2	216	218
1.65	0.85	6.18	7.02	0.00	0.15	0.15	1	181	182
1.70	0.85	6.30	7.15	0.00	0.12	0.13	1	150	151
1.75	0.85	6.40	7.25	0.00	0.10	0.10	0	123	123
1.80	0.85	6.49	7.34	0.00	0.08	0.08	0	101	101
1.85	0.85	6.56	7.40	0.00	0.07	0.07	0	82	82
1.90	0.85	6.61	7.46	0.00	0.05	0.06	0	66	66
1.95	0.85	6.65	7.50	0.00	0.04	0.04	0	53	53
2.00	0.85	6.69	7.54	0.	0.03	0.03	0	42	42
2.05	0.85	6.72	7.57	0.	0.03	0.03	0	33	33
2.10	0.85	6.74	7.59	0.	0.02	0.02	0	26	26
2.15	0.85	6.76	7.60	0.	0.02	0.02	0	20	20
2.20	0.85	6.77	7.62	0.	0.01	0.01	0	16	16
2.25	0.85	6.78	7.63	0.	0.01	0.01	0	12	12
2.30	0.85	6.79	7.64	0.	0.01	0.01	0	9	9
2.35	0.85	6.79	7.64	0.	0.01	0.01	0	7	7
2.40	0.85	6.80	7.65	0.	0.00	0.00	0	5	5
2.45	0.85	6.80	7.65	0.	0.00	0.00	0	4	4
2.50	0.85	6.81	7.65	0.	0.00	0.00	0	3	3
2.55	0.85	6.81	7.66	0.	0.00	0.00	0	2	2
2.60	0.85	6.81	7.66	0.	0.00	0.00	0	1	1
2.65	0.85	6.81	7.66	0.	0.00	0.00	0	1	1
2.70	0.85	6.81	7.66	0.	0.00	0.00	0	1	1

Table 14

Surface Flow Time History, Grid Sequence 1355, for a 0.05-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME HOUR	SURFACE FLOW, IN CUMULATIVE RAIN	CUMULATIVE MOVE	CUMULATIVE TOTAL	INCREMENTAL RAIN	INCREMENTAL MOVE	INCREMENTAL TOTAL	INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.05	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.15	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.25	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.35	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.45	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.01	0.00	0.01	0.01	0.00	0.01	8	1	9
0.55	0.03	0.01	0.04	0.02	0.01	0.03	26	9	35
0.60	0.06	0.03	0.09	0.03	0.02	0.05	40	25	65
0.65	0.11	0.07	0.18	0.04	0.04	0.09	52	51	103
0.70	0.16	0.14	0.30	0.05	0.07	0.12	62	86	148
0.75	0.22	0.25	0.47	0.06	0.11	0.16	70	128	198
0.80	0.28	0.40	0.68	0.06	0.15	0.21	77	177	254
0.85	0.35	0.59	0.94	0.07	0.19	0.26	84	234	318
0.90	0.42	0.84	1.26	0.07	0.25	0.32	89	299	388
0.95	0.50	1.15	1.65	0.08	0.31	0.38	94	371	465
1.00	0.58	1.52	2.10	0.08	0.37	0.45	98	450	548
1.05	0.66	1.96	2.63	0.08	0.44	0.52	99	535	634
1.10	0.73	2.47	3.20	0.06	0.51	0.57	78	611	689
1.15	0.77	3.02	3.79	0.04	0.56	0.59	47	672	719
1.20	0.79	3.61	4.41	0.02	0.59	0.62	26	717	743
1.25	0.81	4.24	5.04	0.01	0.62	0.64	17	754	771
1.30	0.82	4.89	5.70	0.01	0.65	0.66	13	786	799
1.35	0.83	5.56	6.38	0.01	0.67	0.68	10	811	821
1.40	0.83	6.25	7.08	0.01	0.69	0.69	8	831	839
1.45	0.84	6.94	7.78	0.00	0.70	0.70	5	842	847
1.50	0.84	7.64	8.48	0.00	0.70	0.70	4	844	848
1.55	0.84	8.33	9.18	0.00	0.69	0.69	3	837	840
1.60	0.85	9.01	9.86	0.00	0.68	0.68	2	820	822
1.65	0.85	9.67	10.51	0.00	0.66	0.66	1	793	794
1.70	0.85	10.29	11.14	0.00	0.63	0.63	1	757	758
1.75	0.85	10.88	11.73	0.00	0.59	0.59	0	715	715
1.80	0.85	11.44	12.28	0.00	0.55	0.55	0	668	668
1.85	0.85	11.95	12.79	0.00	0.51	0.51	0	617	617
1.90	0.85	12.41	13.26	0.00	0.47	0.47	0	565	565
1.95	0.85	12.84	13.69	0.00	0.42	0.42	0	512	512
2.00	0.85	13.22	14.07	0.	0.38	0.38	0	461	461
2.05	0.85	13.56	14.41	0.	0.34	0.34	0	411	411
2.10	0.85	13.86	14.71	0.	0.30	0.30	0	364	364
2.15	0.85	14.12	14.97	0.	0.27	0.27	0	320	320
2.20	0.85	14.36	15.21	0.	0.23	0.23	0	280	280
2.25	0.85	14.56	15.41	0.	0.20	0.20	0	244	244
2.30	0.85	14.73	15.58	0.	0.17	0.17	0	211	211
2.35	0.85	14.88	15.73	0.	0.15	0.15	0	182	182
2.40	0.85	15.01	15.86	0.	0.13	0.13	0	156	156
2.45	0.85	15.12	15.97	0.	0.11	0.11	0	133	133
2.50	0.85	15.22	16.07	0.	0.09	0.09	0	113	113
2.55	0.85	15.30	16.14	0.	0.08	0.08	0	96	96
2.60	0.85	15.36	16.21	0.	0.07	0.07	0	81	81
2.65	0.85	15.42	16.27	0.	0.06	0.06	0	68	68
2.70	0.85	15.47	16.32	0.	0.05	0.05	0	57	57

Table 15

Surface Flow Time History, Grid Sequence 1317, for a 0.10-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME HOUR	SURFACE FLOW, IN CUMULATIVE RAIN	CUMULATIVE MOVE	CUMULATIVE TOTAL	INCREMENTAL RAIN	INCREMENTAL MOVE	INCREMENTAL TOTAL	INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.02	0.00	0.02	0.02	0.00	0.02	10	0	10
0.60	0.08	0.01	0.09	0.07	0.01	0.07	40	3	43
0.70	0.19	0.02	0.20	0.10	0.01	0.11	62	6	68
0.80	0.31	0.03	0.35	0.13	0.01	0.14	77	9	86
0.90	0.46	0.05	0.51	0.15	0.02	0.17	89	10	99
1.00	0.62	0.07	0.70	0.16	0.02	0.18	98	12	110
1.10	0.75	0.09	0.84	0.13	0.02	0.15	78	10	88
1.20	0.80	0.10	0.90	0.04	0.01	0.05	26	6	32
1.30	0.82	0.10	0.93	0.02	0.01	0.03	13	3	16
1.40	0.83	0.11	0.94	0.01	0.00	0.02	8	1	9
1.50	0.84	0.11	0.95	0.01	0.00	0.01	4	0	4
1.60	0.85	0.11	0.95	0.00	0.00	0.01	2	0	2
1.70	0.85	0.11	0.96	0.00	0.00	0.00	1	0	1
1.80	0.85	0.11	0.96	0.00	0.00	0.00	0	0	0
1.90	0.85	0.11	0.96	0.00	0.00	0.00	0	0	0
2.00	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.10	0.85	0.11	0.96	0.	0.00	0.00	0	0	0
2.20	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.30	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.40	0.85	0.11	0.95	0.	0.	0.	0	0	0
2.50	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.60	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.70	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.80	0.85	0.11	0.96	0.	0.	0.	0	0	0

Table 16

Surface Flow Time History, Grid Sequence 1318, for a 0.10-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME HOUR	SURFACE FLOW, IN CUMULATIVE RAIN	CUMULATIVE MOVE	CUMULATIVE TOTAL	INCREMENTAL RAIN	INCREMENTAL MOVE	INCREMENTAL TOTAL	INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.02	0.01	0.03	0.02	0.01	0.03	10	8	18
0.60	0.08	0.07	0.15	0.07	0.06	0.12	40	34	74
0.70	0.19	0.17	0.36	0.10	0.10	0.20	62	60	122
0.80	0.31	0.31	0.62	0.13	0.13	0.26	77	81	158
0.90	0.46	0.47	0.93	0.15	0.16	0.31	89	97	186
1.00	0.62	0.65	1.27	0.16	0.18	0.34	98	109	207
1.10	0.75	0.81	1.56	0.13	0.16	0.29	78	96	174
1.20	0.80	0.89	1.69	0.04	0.08	0.13	26	50	76
1.30	0.82	0.94	1.76	0.02	0.04	0.07	13	26	39
1.40	0.83	0.96	1.80	0.01	0.02	0.04	8	14	22
1.50	0.84	0.97	1.82	0.01	0.01	0.02	4	7	11
1.60	0.85	0.98	1.83	0.00	0.01	0.01	2	4	6
1.70	0.85	0.99	1.83	0.00	0.00	0.01	1	2	3
1.80	0.85	0.99	1.84	0.00	0.00	0.00	0	1	1
1.90	0.85	0.99	1.84	0.00	0.00	0.00	0	0	0
2.00	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.10	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.20	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.30	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.40	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.50	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.60	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.70	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.80	0.85	0.99	1.84	0.	0.	0.	0	0	0

Table 17

Surface Flow Time History, Grid Sequence 1325, for a 0.10-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME HOUR	SURFACE FLOW, IN: CUMULATIVE RAIN	CUMULATIVE MOVE	CUMULATIVE TOTAL	INCREMENTAL RAIN	INCREMENTAL MOVE	INCREMENTAL TOTAL	INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE: RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.	0.02	0.02	0.	0.02	0.02	0	13	13
0.60	0.01	0.13	0.14	0.01	0.10	0.12	8	62	70
0.70	0.06	0.34	0.40	0.05	0.21	0.26	29	127	156
0.80	0.14	0.70	0.84	0.08	0.36	0.44	46	220	266
0.90	0.24	1.26	1.49	0.10	0.55	0.65	59	335	394
1.00	0.35	2.04	2.40	0.12	0.79	0.90	69	477	546
1.10	0.45	3.04	3.49	0.10	1.00	1.10	58	605	663
1.20	0.48	4.15	4.64	0.03	1.11	1.14	20	671	691
1.30	0.50	5.34	5.85	0.02	1.19	1.21	10	720	730
1.40	0.51	6.57	7.08	0.01	1.23	1.24	6	741	747
1.50	0.52	7.76	8.28	0.01	1.19	1.20	3	720	723
1.60	0.52	8.84	9.36	0.00	1.08	1.08	2	651	653
1.70	0.52	9.73	10.25	0.00	0.89	0.89	0	540	540
1.80	0.52	10.41	10.93	0.00	0.68	0.68	0	409	409
1.90	0.52	10.88	11.40	0.00	0.47	0.47	0	285	285
2.00	0.52	11.19	11.71	0.	0.31	0.31	0	186	186
2.10	0.52	11.38	11.90	0.	0.19	0.19	0	116	116
2.20	0.52	11.50	12.02	0.	0.12	0.12	0	70	70
2.30	0.52	11.56	12.09	0.	0.07	0.07	0	41	41
2.40	0.52	11.60	12.13	0.	0.04	0.04	0	25	25
2.50	0.52	11.62	12.15	0.	0.02	0.02	0	12	12
2.60	0.52	11.64	12.16	0.	0.01	0.01	0	6	6
2.70	0.52	11.64	12.16	0.	0.01	0.01	0	3	3
2.80	0.52	11.64	12.17	0.	0.00	0.00	0	1	1

Table 18

Surface Flow Time History, Grid Sequence 1331, for a 0.10-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME HOUR	SURFACE FLOW, IN: CUMULATIVE RAIN	CUMULATIVE MOVE	CUMULATIVE TOTAL	INCREMENTAL RAIN	INCREMENTAL MOVE	INCREMENTAL TOTAL	INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE: RAIN	MOVE	TOTAL
1.00	0.35	0.58	0.93	0.12	0.21	0.33	69	129	198
1.10	0.45	0.83	1.28	0.10	0.26	0.35	58	154	212
1.20	0.48	1.10	1.58	0.03	0.26	0.30	20	158	178
1.30	0.50	1.36	1.86	0.02	0.27	0.29	10	162	172
1.40	0.51	1.62	2.14	0.01	0.26	0.27	6	157	163
1.50	0.52	1.86	2.38	0.01	0.24	0.24	3	144	147
1.60	0.52	2.07	2.59	0.00	0.21	0.21	2	127	129
1.70	0.52	2.25	2.77	0.00	0.18	0.18	0	108	108
1.80	0.52	2.40	2.92	0.00	0.15	0.15	0	90	90
1.90	0.52	2.52	3.05	0.00	0.12	0.12	0	74	74
2.00	0.52	2.63	3.15	0.	0.10	0.10	0	61	61
2.10	0.52	2.71	3.23	0.	0.08	0.08	0	50	50
2.20	0.52	2.78	3.30	0.	0.07	0.07	0	41	41
2.30	0.52	2.83	3.36	0.	0.06	0.06	0	33	33
2.40	0.52	2.88	3.40	0.	0.05	0.05	0	27	27
2.50	0.52	2.92	3.44	0.	0.04	0.04	0	22	22
2.60	0.52	2.95	3.47	0.	0.03	0.03	0	18	18
2.70	0.52	2.97	3.49	0.	0.03	0.03	0	15	15
2.80	0.52	2.99	3.52	0.	0.02	0.02	0	12	12
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.00	0.00	0.	0.00	0.00	0	0	0
0.50	0.	0.01	0.01	0.	0.01	0.01	0	4	4
0.60	0.01	0.04	0.05	0.01	0.03	0.04	8	16	24
0.70	0.06	0.10	0.15	0.05	0.06	0.11	29	38	67
0.80	0.14	0.21	0.35	0.08	0.11	0.18	46	64	110
0.90	0.24	0.36	0.60	0.10	0.16	0.26	59	95	154

Table 19

Surface Flow Time History, Grid Sequence 1342, for a 0.10-Hour Time Increment

SURFACE FLOW TIME HISTORY									
	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.02	0.01	0.03	0.02	0.01	0.03	10	7	17
0.60	0.08	0.09	0.18	0.07	0.08	0.15	40	48	88
0.70	0.19	0.31	0.49	0.10	0.22	0.32	62	130	192
0.80	0.31	0.71	1.02	0.13	0.40	0.53	77	240	317
0.90	0.46	1.32	1.78	0.15	0.62	0.76	89	372	461
1.00	0.62	2.17	2.79	0.16	0.85	1.01	98	512	610
1.10	0.75	3.17	3.92	0.13	1.00	1.13	78	604	682
1.20	0.80	4.14	4.94	0.04	0.97	1.01	26	586	612
1.30	0.82	4.97	5.79	0.02	0.83	0.85	13	502	515
1.40	0.83	5.60	6.44	0.01	0.64	0.65	8	385	393
1.50	0.84	6.05	6.89	0.01	0.45	0.45	4	270	274
1.60	0.85	6.35	7.19	0.00	0.30	0.30	2	179	181
1.70	0.85	6.54	7.38	0.00	0.19	0.19	1	114	115
1.80	0.85	6.65	7.50	0.00	0.12	0.12	0	70	70
1.90	0.85	6.72	7.57	0.00	0.07	0.07	0	42	42
2.00	0.85	6.76	7.61	0.	0.04	0.04	0	24	24
2.10	0.85	6.79	7.63	0.	0.02	0.02	0	13	13
2.20	0.85	6.80	7.65	0.	0.01	0.01	0	7	7
2.30	0.85	6.80	7.65	0.	0.01	0.01	0	3	3
2.40	0.85	6.81	7.66	0.	0.00	0.00	0	2	2
2.50	0.85	6.81	7.66	0.	0.00	0.00	0	1	1
2.60	0.85	6.81	7.66	0.	0.00	0.00	0	0	0
2.70	0.85	6.81	7.66	0.	0.00	0.00	0	0	0
2.80	0.85	6.81	7.66	0.	0.00	0.00	0	0	0

Table 20

Surface Flow Time History, Grid Sequence 1355, for a 0.10-Hour Time Increment

SURFACE FLOW TIME HISTORY									
	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.10	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.30	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.	0.	0.	0.	0.	0	0	0
0.50	0.02	0.01	0.02	0.02	0.01	0.02	10	3	13
0.60	0.08	0.05	0.13	0.07	0.05	0.11	40	27	67
0.70	0.19	0.20	0.38	0.10	0.15	0.25	62	88	150
0.80	0.31	0.49	0.80	0.13	0.29	0.42	77	174	251
0.90	0.46	0.96	1.42	0.15	0.47	0.62	89	285	374
1.00	0.62	1.66	2.28	0.16	0.70	0.86	98	422	520
1.10	0.75	2.58	3.34	0.13	0.93	1.05	78	559	637
1.20	0.80	3.66	4.46	0.04	1.08	1.13	26	655	681
1.30	0.82	4.87	5.69	0.02	1.20	1.23	13	728	741
1.40	0.83	6.17	7.00	0.01	1.30	1.32	8	787	795
1.50	0.84	7.53	8.38	0.01	1.36	1.37	4	825	829
1.60	0.85	8.91	9.76	0.00	1.38	1.38	2	833	835
1.70	0.85	10.24	11.08	0.00	1.33	1.33	1	801	802
1.80	0.85	11.44	12.29	0.00	1.21	1.21	0	729	729
1.90	0.85	12.48	13.33	0.00	1.03	1.04	0	626	626
2.00	0.85	13.32	14.17	0.	0.84	0.84	0	507	507
2.10	0.85	13.97	14.82	0.	0.65	0.65	0	393	393
2.20	0.85	14.45	15.30	0.	0.49	0.49	0	293	293
2.30	0.85	14.80	15.65	0.	0.35	0.35	0	212	212
2.40	0.85	15.05	15.90	0.	0.25	0.25	0	149	149
2.50	0.85	15.22	16.07	0.	0.17	0.17	0	103	103
2.60	0.85	15.34	16.19	0.	0.12	0.12	0	70	70
2.70	0.85	15.42	16.27	0.	0.08	0.08	0	46	46
2.80	0.85	15.47	16.32	0.	0.05	0.05	0	30	30

Table 21

Surface Flow Time History, Grid Sequence 1317, for a 0.20-Hour Time Increment

TIME HOUR	SURFACE FLOW, IN — CUMULATIVE RAIN	CUMULATIVE MOVE	CUMULATIVE TOTAL	INCREMENTAL RAIN	INCREMENTAL MOVE	INCREMENTAL TOTAL	INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
0.60	0.13	0.02	0.15	0.13	0.02	0.14	38	4	42
0.80	0.39	0.05	0.44	0.26	0.03	0.29	78	10	88
1.00	0.72	0.09	0.81	0.33	0.04	0.37	100	13	113
1.20	0.81	0.11	0.92	0.09	0.01	0.10	27	3	30
1.40	0.84	0.11	0.95	0.03	0.00	0.03	8	1	9
1.60	0.85	0.11	0.96	0.01	0.00	0.01	2	0	2
1.80	0.85	0.11	0.96	0.00	0.00	0.00	0	0	0
2.00	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.20	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.40	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.60	0.85	0.11	0.96	0.	0.	0.	0	0	0
2.80	0.85	0.11	0.96	0.	0.	0.	0	0	0
3.00	0.85	0.11	0.96	0.	0.	0.	0	0	0
3.20	0.85	0.11	0.96	0.	0.	0.	0	0	0
3.40	0.85	0.11	0.96	0.	0.	0.	0	0	0
3.60	0.85	0.11	0.96	0.	0.	0.	0	0	0

Table 22

Surface Flow Time History, Grid Sequence 1318, for a 0.20-Hour Time Increment

TIME HOUR	SURFACE FLOW, IN — CUMULATIVE RAIN	CUMULATIVE MOVE	CUMULATIVE TOTAL	INCREMENTAL RAIN	INCREMENTAL MOVE	INCREMENTAL TOTAL	INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
0.60	0.13	0.13	0.26	0.13	0.13	0.26	38	39	77
0.80	0.39	0.42	0.81	0.26	0.29	0.55	78	86	164
1.00	0.72	0.80	1.52	0.33	0.38	0.71	100	114	214
1.20	0.81	0.93	1.74	0.09	0.13	0.22	27	40	67
1.40	0.84	0.97	1.81	0.03	0.04	0.07	8	12	20
1.60	0.85	0.99	1.83	0.01	0.01	0.02	2	4	6
1.80	0.85	0.99	1.84	0.00	0.00	0.01	0	0	0
2.00	0.85	0.99	1.84	0.	0.00	0.00	0	0	0
2.20	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.40	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.60	0.85	0.99	1.84	0.	0.	0.	0	0	0
2.80	0.85	0.99	1.84	0.	0.	0.	0	0	0
3.00	0.85	0.99	1.84	0.	0.	0.	0	0	0
3.20	0.85	0.99	1.84	0.	0.	0.	0	0	0
3.40	0.85	0.99	1.84	0.	0.	0.	0	0	0
3.60	0.85	0.99	1.84	0.	0.	0.	0	0	0

Table 23

Surface Flow Time History, Grid Sequence 1325, for a 0.20-Hour Time Increment

SURFACE FLOW TIME HISTORY									
	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.00	0.00	0.	0.00	0.00	0	0	0
0.60	0.03	0.19	0.22	0.03	0.19	0.22	10	56	66
0.80	0.19	0.69	0.88	0.15	0.51	0.66	46	153	199
1.00	0.42	1.69	2.11	0.24	0.99	1.23	71	300	371
1.20	0.49	2.87	3.36	0.07	1.18	1.25	20	357	377
1.40	0.51	4.21	4.72	0.02	1.34	1.36	6	404	410
1.60	0.52	5.67	6.19	0.01	1.46	1.47	2	442	444
1.80	0.52	7.21	7.74	0.00	1.54	1.55	0	467	467
2.00	0.52	8.71	9.24	0.	1.50	1.50	0	454	454
2.20	0.52	9.99	10.51	0.	1.27	1.27	0	385	385
2.40	0.52	10.87	11.40	0.	0.88	0.88	0	267	267
2.60	0.52	11.34	11.87	0.	0.47	0.47	0	142	142
2.80	0.52	11.54	12.07	0.	0.20	0.20	0	60	60
3.00	0.52	11.62	12.14	0.	0.07	0.07	0	21	21
3.20	0.52	11.64	12.16	0.	0.02	0.02	0	6	6
3.40	0.52	11.64	12.17	0.	0.01	0.01	0	1	1
3.60	0.52	11.64	12.17	0.	0.00	0.00	0	0	0

Table 24

Surface Flow Time History, Grid Sequence 1331, for a 0.20-Hour Time Increment

SURFACE FLOW TIME HISTORY									
	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
TIME HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.	0.00	0.00	0.	0.00	0.00	0	0	0
0.60	0.03	0.04	0.07	0.03	0.04	0.07	10	11	21
0.80	0.19	0.18	0.37	0.15	0.14	0.30	46	43	89
1.00	0.42	0.48	0.91	0.24	0.30	0.54	71	90	161
1.20	0.49	0.85	1.34	0.07	0.37	0.44	20	111	131
1.40	0.51	1.28	1.80	0.02	0.43	0.45	6	131	137
1.60	0.52	1.73	2.25	0.01	0.44	0.45	2	133	135
1.80	0.52	2.11	2.63	0.00	0.38	0.38	0	115	115
2.00	0.52	2.40	2.92	0.	0.29	0.29	0	88	88
2.20	0.52	2.61	3.13	0.	0.21	0.21	0	63	63
2.40	0.52	2.75	3.27	0.	0.14	0.14	0	42	42
2.60	0.52	2.84	3.37	0.	0.09	0.09	0	28	28
2.80	0.52	2.90	3.43	0.	0.06	0.06	0	18	18
3.00	0.52	2.94	3.46	0.	0.04	0.04	0	11	11
3.20	0.52	2.97	3.49	0.	0.02	0.02	0	7	7
3.40	0.52	2.98	3.51	0.	0.02	0.02	0	4	4
3.60	0.52	2.99	3.52	0.	0.01	0.01	0	3	3

Table 25

Surface Flow Time History, Grid Sequence 1342, for a 0.20-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
0.60	0.13	0.22	0.35	0.13	0.22	0.35	38	67	105
0.80	0.39	1.03	1.42	0.26	0.80	1.06	78	242	320
1.00	0.72	2.60	3.32	0.33	1.58	1.91	100	477	577
1.20	0.81	4.43	5.24	0.09	1.82	1.91	27	551	578
1.40	0.84	5.84	6.68	0.03	1.42	1.44	8	428	436
1.60	0.85	6.50	7.35	0.01	0.65	0.66	2	198	200
1.80	0.85	6.72	7.57	0.00	0.22	0.23	0	67	67
2.00	0.85	6.79	7.64	0.	0.07	0.07	0	20	20
2.20	0.85	6.81	7.66	0.	0.02	0.02	0	5	5
2.40	0.85	6.81	7.66	0.	0.00	0.00	0	0	0
2.60	0.85	6.81	7.66	0.	0.00	0.00	0	0	0
2.80	0.85	6.81	7.66	0.	0.	0.	0	0	0
3.00	0.85	6.81	7.66	0.	0.	0.	0	0	0
3.20	0.85	6.81	7.66	0.	0.	0.	0	0	0
3.40	0.85	6.81	7.66	0.	0.	0.	0	0	0
3.60	0.85	6.81	7.66	0.	0.	0.	0	0	0

Table 26

Surface Flow Time History, Grid Sequence 1355, for a 0.20-Hour Time Increment

SURFACE FLOW TIME HISTORY

TIME	SURFACE FLOW, IN						INCREMENTAL SURFACE FLOW CU FT/MIN/ACRE		
	CUMULATIVE			INCREMENTAL					
HOUR	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL	RAIN	MOVE	TOTAL
0.	0.	0.	0.	0.	0.	0.	0	0	0
0.20	0.	0.	0.	0.	0.	0.	0	0	0
0.40	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
0.60	0.13	0.08	0.21	0.13	0.08	0.21	38	25	63
0.80	0.39	0.52	0.91	0.26	0.43	0.69	78	130	208
1.00	0.72	1.50	2.22	0.33	0.98	1.31	100	297	397
1.20	0.81	2.82	3.63	0.09	1.33	1.42	27	401	428
1.40	0.84	4.34	5.18	0.03	1.52	1.55	8	459	467
1.60	0.85	5.97	6.82	0.01	1.63	1.64	2	493	495
1.80	0.85	7.67	8.52	0.00	1.69	1.69	0	511	511
2.00	0.85	9.41	10.26	0.	1.74	1.74	0	527	527
2.20	0.85	11.14	11.99	0.	1.73	1.73	0	524	524
2.40	0.85	12.72	13.57	0.	1.58	1.58	0	477	477
2.60	0.85	13.96	14.80	0.	1.24	1.24	0	373	373
2.80	0.85	14.75	15.60	0.	0.80	0.80	0	241	241
3.00	0.85	15.18	16.03	0.	0.42	0.42	0	128	128
3.20	0.85	15.37	16.22	0.	0.19	0.19	0	57	57
3.40	0.85	15.44	16.29	0.	0.07	0.07	0	22	22
3.60	0.85	15.47	16.32	0.	0.02	0.02	0	7	7

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